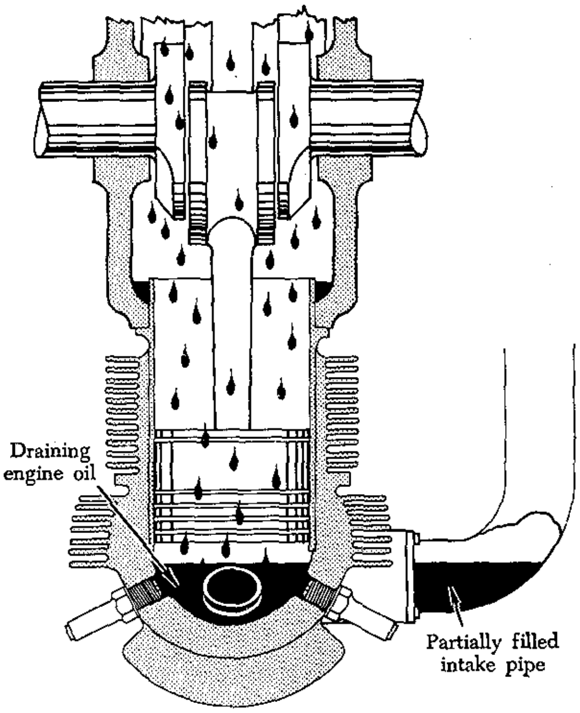


FIGURE 10–44. Initial step in developing a hydraulic lock.

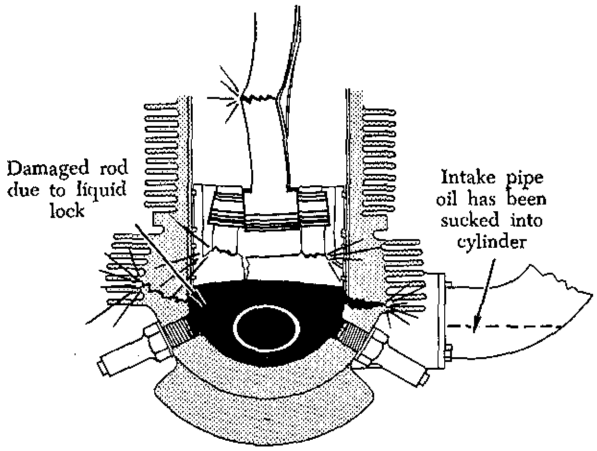


FIGURE 10–45. Results of a hydraulic lock.

A complete hydraulic lock—one that stops crankshaft rotation—can result in serious damage to the engine. Still more serious, however, is the slight damage resulting from a partial hydraulic lock which goes undetected at the time it occurs. The piston meets extremely high resistance but is not completely stopped. The engine falters but starts and continues to run as the other cylinders fire. The slightly bent connecting rod resulting from the partial lock also goes unnoticed at the time it is damaged but is sure to fail later. The eventual failure is almost certain to occur at a time when it can be least tolerated, since it is during such critical operations as takeoff and go-around that maximum power is demanded of the engine and maximum stresses are imposed on its parts. A hydraulic lock and some possible results are shown in figure 10–45.

Before starting any radial engine that has been shut down for more than 30 min., check the ignition switches for "off" and then pull the propeller through in the direction of rotation a minimum of two complete turns to make sure that there is no hydraulic lock or to detect the hydraulic lock if one is present. Any liquid present in a cylinder will be indicated by the abnormal effort required to rotate the propeller. However, never use force when a hydraulic lock is detected. When engines which employ direct drive or combination inertia and direct drive starters are being started, and an external power source is being used, a check for hydraulic lock may be made by intermittently energizing the starter and watching for a tendency of the engine to stall. Use of the starter in this way will not exert sufficient force on the crankshaft to bend or break a connecting rod if a lock is present.

To eliminate a lock, remove either the front or rear spark plug of the lower cylinders and pull the propeller through in the direction of rotation. The piston will expel any liquid that may be present.

If the hydraulic lock occurs as a result of overpriming prior to initial engine start, eliminate the lock in the same manner, *i.e.*, remove one of the spark plugs from the cylinder and rotate the crankshaft through two turns.

Never attempt to clear the hydraulic lock by pulling the propeller through in the direction opposite to normal rotation, since this tends to inject the liquid from the cylinder into the intake pipe with the possibility of a complete or partial lock occurring on the subsequent start.

Valve Blow-by

Valve blow-by is indicated by a hissing or whistle when pulling the propeller through prior to starting the engine, when turning the engine with the starter, or when running the engine at slow speeds. It is caused by a valve sticking open or warped to the extent that compression is not built up in the cylinder as the piston moves toward top dead center on the compression stroke. Blow-by past the exhaust valve can be heard at the exhaust stack, and blow-by past the intake valve is audible through the carburetor.

Correct valve blow-by immediately to prevent valve failure and possible engine failure by taking the following steps:

(1) Perform a cylinder compression test to locate the faulty cylinder.

(2) Check the valve clearance on the affected cylinder. If the valve clearance is incorrect, the valve may be sticking in the valve guide. To release the sticking valve, place a fiber drift on the rocker arm immediately over the valve stem and strike the drift several times with a mallet. Sufficient hand pressure should be exerted on the fiber drift to remove any space between the rocker arm and the valve stem prior to hitting the drift.

(3) If the valve is not sticking and the valve clearance is incorrect, adjust it as necessary.

(4) Determine whether blow-by has been eliminated by again pulling the engine through by hand or turning it with the starter. If blow-by is still present, it may be necessary to replace the cylinder.

CYLINDER COMPRESSION TESTS

The cylinder compression test determines if the valves, piston rings, and pistons are adequately sealing the combustion chamber. If pressure leakage is excessive, the cylinder cannot develop its full power. The purpose of testing cylinder compression is to determine whether cylinder replacement is necessary. The detection and replacement of defective cylinders will prevent a complete engine change because of cylinder failure. It is essential that cylinder compression tests be made periodically.

Although it is possible for the engine to lose compression for other reasons, low compression for the most part can be traced to leaky valves. Conditions which affect engine compression are:

(1) Incorrect valve clearances.

(2) Worn, scuffed, or damaged piston.

(3) Excessive wear of piston rings and cylinder walls.

(4) Burned or warped valves.

(5) Carbon particles between the face and the seat of the valve or valves.

(6) Early or late valve timing.

Perform a compression test as soon as possible after the engine is shut down so that piston rings, cylinder walls, and other parts are still freshly lubricated. However, it is not necessary to operate the engine prior to accomplishing compression checks during engine buildup or on individually replaced cylinders. In such cases, before making the test, spray a small quantity of lubricating oil into the cylinder or cylinders and turn the engine over several times to seal the piston and rings in the cylinder barrel.

Be sure that the ignition switch is in the "off" position so that there will be no accidental firing of the engine. Remove necessary cowling and the most accessible spark plug from each cylinder. When removing the spark plugs, identify them to coincide with the cylinder. Close examination of the plugs will aid in diagnosing problems within the cylinder. Review the maintenance records of the engine being tested. Records of previous compression checks help in determining progressive wear conditions and in establishing the necessary maintenance actions.

The two basic types of compression testers currently in use for checking cylinder compression in aircraft engines are the direct compression tester and the differential pressure tester. The procedures and precautions to observe when using either of these types of testers are outlined in this section. When performing a compression test, follow the manufacturer's instructions for the particular tester being used.

Direct Compression Tester

This type of compression test indicates the actual pressures within the cylinder. Although the particular defective component within the cylinder is difficult to determine with this method, the consistency of the readings for all cylinders is an indication of the condition of the engine as a whole. The following are suggested guidelines for performing a direct compression test:

(1) Warm up the engine to operating temperatures and perform the test as soon as possible after shutdown.

(2) Remove the most accessible spark plug from each cylinder.

(3) Rotate the engine with the starter to expel any excess oil or loose carbon in the cylinders.

(4) If a complete set of compression testers is available, install one tester in each cylinder. However, if only one tester is being used, check each cylinder in turn.

(5) Using the engine starter, rotate the engine at least three complete revolutions and record the compression reading. Use an external power source, if possible, as a low battery will result in a slow engine-turning rate and lower readings.

(6) Re-check any cylinder which shows an abnor-

mal reading when compared with the others. Any cylinder having a reading approximately 15 p.s.i. lower than the others should be suspected of being defective.

(7) If a compression tester is suspected of being defective, replace it with one known to be accurate, and re-check the compression of the affected cylinders.

Differential Pressure Tester

The differential pressure tester checks the compression of aircraft engines by measuring the leakage through the cylinders. The design of this compression tester is such that minute valve leakages can be detected, making possible the replacement of cylinders where valve burning is starting.

The operation of the compression tester is based on the principle that, for any given airflow through a fixed orifice, a constant pressure drop across the orifice will result. As the airflow varies, the pressure changes accordingly and in the same direction. If air is supplied under pressure to the cylinder with both intake and exhaust valves closed, the amount of air that leaks by the valves or piston rings indicates their condition; the perfect cylinder, of course, would have no leakage.

The differential pressure tester (figure 10–46) requires the application of air pressure to the cylinder being tested with the piston at top-center compression stroke.

Guidelines for performing a differential compression test are:

(1) Perform the compression test as soon as possible after engine shutdown to provide uniform lubrication of cylinder walls and rings.

(2) Remove the most accessible spark plug from the cylinder or cylinders and install a spark plug adapter in the spark plug insert.

(3) Connect the compression tester assembly to a 100- to 150-p.s.i. compressed air supply. With the shutoff valve on the compression tester closed, adjust the regulator of the compression tester to obtain 80 p.s.i. on the regulated pressure gage.

(4) Open the shutoff valve and attach the air hose quick-connect fitting to the spark plug adapter. The shutoff valve, when open, will automatically maintain a pressure of 15 to 20 p.s.i. in the cylinder when both the intake and exhaust valves are closed.

(5) By hand, turn the engine over in the direction of rotation until the piston in the cylinder being tested comes up on the compression stroke against the 15 p.s.i. Continue turning the propeller slowly in the direction of rotation until the piston reaches top dead center. Top dead center can be detected by a decrease in force required to move the propeller. If the engine is rotated past top dead center, the 15 to 20 p.s.i. will tend to move the propeller in the direction of rotation. If this occurs, back the propeller up at least one blade prior to turning the propeller again in the direction of rotation. This backing up is necessary to eliminate the effect of backlash in the valve-operating mechanism and to keep the piston rings seated on the lower ring lands.

(6) Close the shutoff valve in the compression tester and re-check the regulated pressure to see that it is 80 p.s.i. with air flowing into the cylinder. If the regulated pressure is more or less than 80 p.s.i., re-adjust the regulator in the test unit to obtain 80 p.s.i. When closing the shutoff valve, make sure that the propeller path is clear of all objects. There will be sufficient air pressure in the combustion chamber to rotate the propeller if the piston is not on top dead center.

(7) With regulated pressure adjusted to 80 p.s.i., if the cylinder pressure reading indicated on the cylinder pressure gage is below the minimum specified for the engine being tested, move the propeller in the direction of rotation to seat the piston rings in the grooves. Check all the cylinders and record the readings.

If low compression is obtained on any cylinder, turn the engine through with the starter or re-start and run the engine to takeoff power and re-check the cylinder or cylinders having low compression.

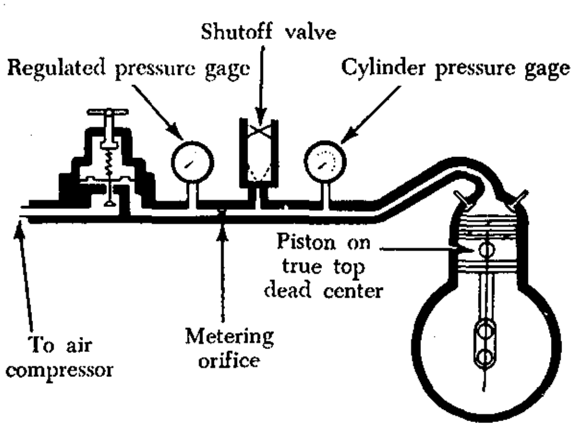


FIGURE 10–46. Differential compression tester.

If the low compression is not corrected, remove the rocker-box cover and check the valve clearance to determine if the difficulty is caused by inadequate valve clearance. If the low compression is not caused by inadequate valve clearance, place a fiber drift on the rocker arm immediately over the valve stem and tap the drift several times with a 1- to 2-pound hammer to dislodge any foreign material that may be lodged between the valve and valve seat. After staking the valve in this manner, rotate the engine with the starter and re-check the compression. Do not make a compression check after staking a valve until the crankshaft has been rotated either with the starter or by hand to re-seat the valve in normal manner. The higher seating velocity obtained when staking the valve will indicate valve seating even though valve seats are slightly egged or eccentric.

Cylinders having compression below the minimum specified after staking should be further checked to determine whether leakage is past the exhaust valve, intake valve, or piston. Excessive leakage can be detected: (1) at the exhaust valve by listening for air leakage at the exhaust outlet; (2) at the intake valve by escaping air at the air intake; and (3) past the piston rings by escaping air at the engine breather outlets.

The wheeze test is another method of detecting leaking intake and exhaust valves. In this test, as the piston is moved to top dead center on the compression stroke, the faulty valve may be detected by listening for a wheezing sound in the exhaust outlet or intake duct.

Another method is to admit compressed air into the cylinder through the spark plug hole. The piston should be restrained at top dead center of the compression stroke during this operation. A leaking valve or piston rings can be detected by listening at the exhaust outlet, intake duct, or engine breather outlets.

Next to valve blow-by, the most frequent cause of compression leakage is excessive leakage past the piston. This leakage may occur because of lack of oil. To check this possibility, squirt engine oil into the cylinder and around the piston. Then re-check the compression. If this procedure raises compression to or above the minimum required, continue the cylinder in service. If the cylinder pressure readings still do not meet the minimum requirement, replace the cylinder. When it is necessary to replace a cylinder as a result of low compression, record the cylinder number and the compression value of the newly installed cylinder on the compression checksheet.

Cylinder Replacement

Reciprocating engine cylinders are designed to operate a specified time before normal wear will require their overhaul. If the engine is operated as recommended and proficient maintenance is performed, the cylinders normally will last until the engine is removed for "high-time" reasons. It is known from experience that materials fail and engines are abused through incorrect operation; this has a serious effect on cylinder life. Another reason for premature cylinder change is poor maintenance. Therefore, exert special care to ensure that all the correct maintenance procedures are adhered to when working on the engine.

Some of the reasons for cylinder replacement are:

(1) Low compression.
(2) High oil consumption in one or more cylinders.
(3) Excessive valve guide clearance.
(4) Loose intake pipe flanges.
(5) Loose or defective spark plug inserts.
(6) External damage, such as cracks.

When conditions like these are limited to one or a few cylinders, replacing the defective cylinders should return the engine to a serviceable condition.

The number of cylinders that can be replaced on air-cooled, in-service engines more economically than changing engines is controversial. Experience has indicated that, in general, one-fourth to one-third of the cylinders on an engine can be replaced economically. Consider these factors when making a decision:

(1) Time on the engine.
(2) Priority established for returning the aircraft to service.
(3) Availability of spare cylinders and spare engines.
(4) Whether QECA (quick engine change assemblies) are being used.
(5) The number of persons available to make the change.

When spare serviceable cylinders are available, replace cylinders when the man-hour requirement for changing them does not exceed the time required to make a complete engine change.

The cylinder is always replaced as a complete assembly, which includes piston, rings, valves, and valve springs. Obtain the cylinder by ordering the cylinder assembly under the part number specified in the engine parts catalog.

Except under certain conditions, do not attempt to replace individual parts, such as pistons, rings, or valves. This precaution guarantees that clearances and tolerances are correct. Other parts, such as valve springs, rocker arms, and rocker box covers, may be replaced individually.

Normally, all the cylinders in an engine are similar; that is, all are standard size or all a certain oversize, and all are steel bore or all are chrome-plated. In some instances, because of shortages at the time of overhaul, it may be necessary that engines have two different sizes of cylinder assemblies.

Replace a cylinder with an identical one, if possible. If an identical cylinder is not available, it is permissible to install either a standard or oversize cylinder and piston assembly, since this will not adversely affect engine operation. The size of the cylinder is indicated by a color code around the barrel (figure 10–47) between the attaching flange and the lower barrel cooling fin.

In some instances, air-cooled engines will be equipped with chrome-plated cylinders. Chrome-plated cylinders are usually identified by a paint band around the barrel between the attaching flange and the lower barrel cooling fin. This color band is usually international orange. When installing a chrome-plated cylinder, do not use chrome-plated piston rings. The matched assembly will, of course, include the correct piston rings. However, if a piston ring is broken during cylinder installation, check the cylinder marking to determine what ring, chrome plated or otherwise, is correct for replacement. Similar precautions must be taken to be sure that the correct size rings are installed.

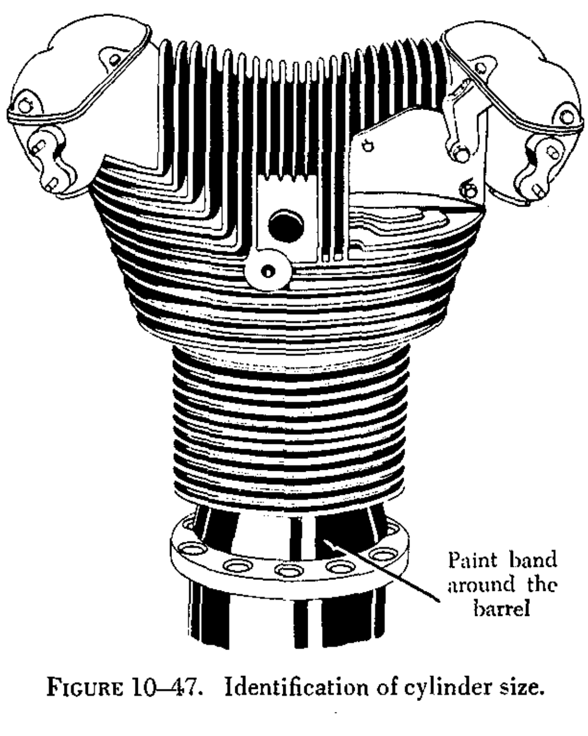


FIGURE 10–47. Identification of cylinder size.

Correct procedures and care are important when replacing cylinders. Careless work or the use of incorrect tools can damage the replacement cylinder or its parts. Incorrect procedures in installing rocker-box covers may result in troublesome oil leaks. Improper torquing of cylinder holddown nuts or capscrews can easily result in a cylinder malfunction and subsequent engine failure.

The discussion of cylinder replacement in this handbook is limited to the removal and installation of air-cooled engine cylinders. The discussion is centered around radial and opposed engines, since these are the aircraft engines on which cylinder replacements are most often performed.

Since these instructions are meant to cover all air-cooled engines, they are necessarily of a general nature. The applicable manufacturer's maintenance manual should be consulted for torque values and special precautions applying to a particular aircraft and engine. However, always practice neatness and cleanliness and always protect openings so that nuts, washers, tools and miscellaneous items do not enter the engine's internal sections.

CYLINDER REMOVAL

Assuming that all obstructing cowling and brackets have been removed, first remove the intake pipe and exhaust pipes. Plug or cover openings in the diffuser section. Then remove cylinder deflectors and any attaching brackets which would obstruct cylinder removal. Loosen the spark plugs and remove the spark-plug lead clamps. Do not remove the spark plugs until ready to pull the cylinder off.

Remove the rocker box covers. First remove the nuts and then tap the cover lightly with a rawhide mallet or plastic hammer. Never pry the cover off with a screwdriver or similar tool.

Loosen the pushrod packing gland nuts or hose clamps, top and bottom. Pushrods are removed by depressing the rocker arms with a special tool or by removing the rocker arm. Before removing the pushrods, turn the crankshaft until the piston is at top dead center on the compression stroke. This relieves the pressure on both intake and exhaust rocker arms. It is also wise to back off the adjusting nut as far as possible, because this allows maximum clearance for pushrod removal when the rocker arms are depressed.

On some model engines, tappets and springs of lower cylinders can fall out. Provision must be made to catch them as the pushrod and housing are removed.

After removing the pushrods, examine them for markings or mark them so that they may be replaced in the same location as they were before removal. The ball ends are usually worn to fit the sockets in which they have been operating. Furthermore, on some engines pushrods are not all of the same length. A good procedure is to mark the pushrods near the valve tappet ends "No. 1 IN," "No. 1 EX," "No. 2 IN," "No. 2 EX," etc.

On fuel injection engines, disconnect the fuel injection line and remove the fuel injection nozzle and any line clamps which will interfere with cylinder removal.

If the cylinder to be removed is a master rod cylinder, special precautions, in addition to regular cylinder removal precautions, must be observed. Information designating which cylinder has the master rod is included on the engine data plate. Arrangements must be made to hold the master rod in the mid-position of the crankcase cylinder hole (after the cylinder has been removed). Templates or guides are usually provided by the manufacturer for this purpose, or they are manufactured locally.

Under no circumstances should the master rod be moved from side to side. It must be kept centered until the guide is in place. Do not turn the crankshaft while the master rod cylinder is removed and other cylinders in the row remain on the engine. These precautions are necessary to prevent bottom rings on some of the other pistons from coming out of the cylinders, expanding, and damaging rings and piston skirts. If several cylinders are to be removed, one of which is the master rod cylinder, it should always be removed last and should be the first installed.

The next step in removing the cylinder is to cut the lockwire or remove the cotter pin, and pry off the locking device from the cylinder-attaching capscrews or nuts. Remove all the screws or nuts except two located 180° apart. Use the wrench specified for this purpose in the special tools section of the applicable manual.

Finally, while supporting the cylinder, remove the two remaining screws or nuts and gently pull the cylinder away from the crankcase. Two men must work together during this step as well as during the remaining procedure for cylinder replacement. After the cylinder skirt has cleared the crankcase and before the piston protrudes from the skirt, provide some means (usually a shop cloth) for preventing pieces of broken rings from falling into the crankcase. After the piston has been removed, remove the cloths and carefully check for piston ring pieces. To make certain that no ring pieces have entered the crankcase, collect and arrange all the pieces to see that they form a complete ring.

Place a support on the cylinder mounting pad and secure it with two capscrews or nuts. Then remove the piston and ring assembly from the connecting rod. When varnish makes it hard to remove the pin, a pin pusher or puller tool must be used. If the special tool is not available and a drift is used to remove the piston pin, the connecting rod should be supported so that it will not have to take the shock of the blows. If this is not done, the rod may be damaged.

After the removal of a cylinder and piston, the connecting rod must be supported to prevent damage to the rod and crankcase. This can be done by supporting each connecting rod with the removed cylinder base oil seal ring looped around the rod and cylinder base studs.

Using a wire brush, clean the studs or capscrews and examine them for cracks, damaged threads, or any other visible defects. If one capscrew is found loose or broken at the time of cylinder removal, all the capscrews for the cylinder should be discarded, since the remaining capscrews may have been seriously weakened. A cylinder holddown stud failure will place the adjacent studs under a greater operating pressure, and they are likely to be stretched beyond their elastic limit. The engine manufacturer's instruction must be followed for the number of studs that will have to be replaced after a stud failure.

When removing a broken stud, take proper precautions to prevent metal chips from entering the engine power section.

In all cases, both faces of the washers and the seating faces of stud nuts or capscrews must be cleaned and any roughness or burrs removed.

CYLINDER INSTALLATION

See that all preservative oil accumulation on the cylinder and piston assembly is washed off with solvent and thoroughly dried with compressed air. Install the piston and ring assembly on the connecting rod. Be sure that the piston faces in the right direction. The piston number stamped on the bottom of the piston head should face toward the front of the engine. Lubricate the piston pin before inserting it. It should fit with a push fit. If a drift must be used, follow the same precaution that was taken during pin removal.

Oil the exterior of the piston assembly generously, forcing oil around the piston rings and in the space between the rings and grooves. Stagger the ring gaps around the piston and check to see that rings are in the correct grooves and whether they are positioned correctly, because some are used as oil scrapers, others as pumper rings. The number, type and arrangement of the compression and oil-control rings will vary with the make and model of engine.

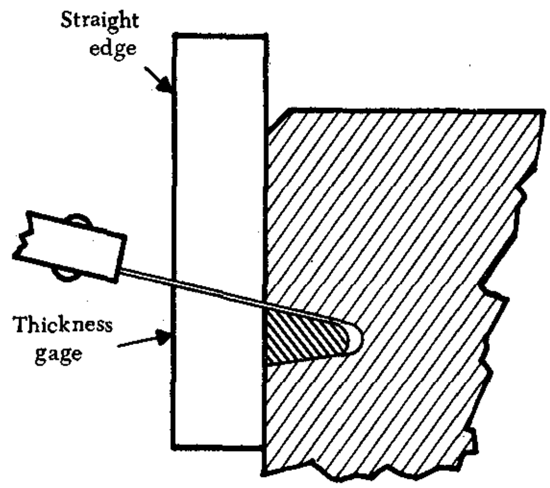
If it is necessary to replace the rings on one or more of the pistons, check the side clearance against the manufacturer's specification, using a thickness gage. The ring end gap must also be checked. The method for checking side and end clearance is shown in figure 10–48. If the ring gage shown is not available, a piston (without rings) may be inserted in the cylinder and the ring inserted in the cylinder bore. Insert the ring in the cylinder skirt below the mounting flange, since this is usually the smallest bore diameter. Pull the piston against the ring to align it properly in the bore.

If it is necessary to remove material to obtain the correct side clearance, it can be done either by turning the piston grooves a slight amount on each side or by lapping the ring on a surface plate.

If the end gap is too close, the excess metal can be removed by clamping a mill file in a vise, holding the ring in proper alignment, and dressing off the ends. In all cases the engine manufacturer's procedures must be followed.

Before installing the cylinder, check the flange to see that the mating surface is smooth and clean. Coat the inside of the cylinder barrel generously with oil. Be sure that the cylinder oil-seal ring is in place and that only one seal ring is used.

Using a ring compressor, compress the rings to a diameter equal to that of the piston. Start the cylinder assembly down over the piston, making certain that the cylinder and piston plane remain the same. Ease the cylinder over the piston with a straight, even movement which will move the ring compressor as the cylinder slips on. Do not rock the cylinder while slipping it on the piston, since any rocking is apt to release a piston ring or a part of a ring from the ring compressor prior to the ring's entrance into the cylinder bore. A ring released in this manner will expand and prevent the piston from entering the cylinder. Any attempt to force the cylinder onto the piston is apt to cause cracking or chipping of the ring or damage to the ring lands.



A.

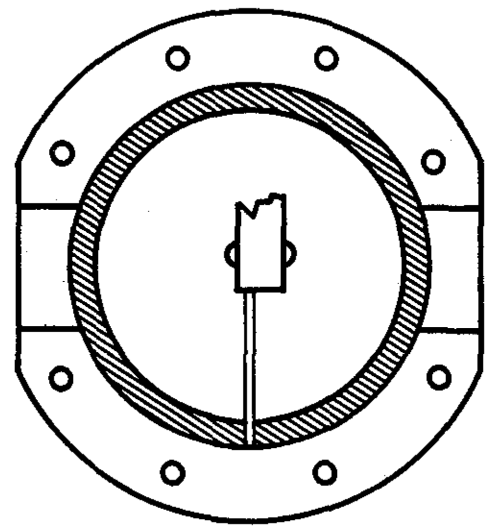

B.

FIGURE 10–48. (A) Measuring piston ring side clearance and (B) end gap.

After the cylinder has slipped on the piston so that all piston rings are in the cylinder bore, remove the ring compressor and the connecting rod guide. Then slide the cylinder into place on the mounting pad. If capscrews are used, rotate the cylinder to align the holes. While still supporting the cylinder, install two capscrews or stud nuts 180° apart.

If the cylinder is secured to the crankcase by conical washers and nuts or capscrews, position the cylinder on the crankcase section by two special locating nuts or capscrews. These locating nuts or capscrews do not remain on the engine, but are removed and replaced with regular nuts or capscrews and conical washers after they have served their purpose and the other nuts or capscrews have been installed and tightened to the prescribed torque.

Install the remaining nuts or capscrews with their conical washers, and tighten the nuts or capscrews until they are snug. Make sure that the conical side of each washer is toward the cylinder mounting flange. Before inserting capscrews, coat them with a good sealer to prevent oil leakage. Generally, studs fit into holes and the fit is tight enough to prevent leakage.

The holddown nuts or capscrews must now be torqued to the value specified in the table of torque values in the engine manufacturer's service or overhaul manual. A definite and specific sequence of tightening all cylinder fastenings must be followed. Always refer to the appropriate engine service manual. A general rule is to tighten the first two nuts or capscrews 180° from each other; then tighten two alternate nuts or capscrews 90° from the first two.

If locating nuts or capscrews are being used, they should be torqued first. The tightening of the remaining screws or nuts should be alternated 180° as the torquing continues around the cylinder. Apply the torque with a slow, steady motion until the prescribed value is reached. Hold the tension on the wrench for a sufficient length of time to ensure that the nut or capscrew will tighten no more at the prescribed torque value. In many cases, additional turning of the capscrew or nut as much as one-quarter turn can be done by maintaining the prescribed torque on the nut for a short period of time. After tightening the regular nuts or capscrews, remove the two locating nuts or capscrews, install regular nuts or capscrews, and tighten them to the prescribed torque.

After the stud nuts or capscrews have been torqued to the prescribed value, safety them in the manner recommended in the engine manufacturer's service manual.

Re-install the push rods, push rod housings, rocker arms, barrel deflectors, intake pipes, ignition harness lead clamps and brackets, fuel injection line clamps and fuel injection nozzles, exhaust stack, cylinder head deflectors, and spark plugs. Remember that the push rods must be installed in their original locations and must not be turned end to end. Make sure, too, that the push rod ball end seats properly in the tappet. If it rests on the edge or shoulder of the tappet during valve clearance adjustment and later drops into place, valve clearance will be off. Furthermore, rotating the crankshaft with the push rod resting on the edge of the tappet may bend the push rod.

After installing the push rods and rocker arms, set the valve clearance.

Before installing the rocker box covers, lubricate the rocker arm bearings and valve stems. Check the rocker box covers for flatness, and re-surface them if necessary. After installing the gaskets and covers, tighten the rocker box cover nuts to the specified torque.

Safety those nuts, screws, and other fasteners which require safetying. Follow the recommended safetying procedures.

VALVE AND VALVE MECHANISM

Valves open and close the ports in the cylinder head to control the entrance of the combustible mixture and the exit of the exhaust gases. It is important that they open and close properly and seal tight against the port seats to secure maximum power from the burning fuel/air mixture for the crankshaft, and to prevent valve burning and warping. The motion of the valves is controlled by the valve-operating mechanism.

The valve mechanism includes cam plates or shafts, cam followers, pushrods, rocker arms, valve springs, and retainers. All parts of a valve mechanism must be in good condition and valve clearances must be correct if the valves are to operate properly.

Checking and adjusting the valve clearance is perhaps the most important part of valve inspection, and certainly it is the most difficult part. However, the visual inspection should not be slighted. It should include a check for the following major items:

(1) Metal particles in the rocker box are indications of excessive wear or partial failure of the valve mechanism. Locate and replace the defective parts.

(2) Excessive side clearance or galling of the rocker arm side. Replace defective rocker arms. Add shims when permitted, to correct excessive side clearance.

(3) Insufficient clearance between the rocker arm and the valve spring retainer. Follow the procedure outlined in the engine service manual for checking this clearance, and increase it to the minimum specified.

(4) Replace any damaged parts, such as cracked, broken, or chipped rocker arms, valve springs, or spring retainers. If the damaged part is one which cannot be replaced in the field, replace the cylinder.

(5) Excessive valve stem clearance. A certain amount of valve stem wobble in the valve guide is normal. Replace the cylinder only in severe cases.

(6) Evidence of incorrect lubrication. Excessive dryness indicates insufficient lubrication. However, the lubrication varies between engines and between cylinders in the same model engine. For example, the upper boxes of radial engines will normally run drier than the lower rocker boxes. These factors must be taken into account in determining whether or not ample lubrication is being obtained. Wherever improper lubrication is indicated, determine the cause and correct it. For example, a dry rocker may be caused by a plugged oil passage in the pushrod. Excessive oil may be caused by plugged drains between the rocker box and the crankcase. If the push rod drains become clogged, the oil forced to the rocker arm and other parts of the valve mechanism cannot drain back to the crankcase. This may result in oil leakage at the rocker box cover or in oil seepage along valve stems into the cylinder or exhaust system, causing excessive oil consumption on the affected cylinder and smoking in the exhaust.

(7) Excessive sludge in the rocker box. This indicates an excessive rocker box temperature, which, in turn, may be caused by improper positioning of cowling or exhaust heat shields or baffles. After correcting the cause of the difficulty, spray the interior of the rocker box with dry cleaning solvent, blow it dry with compressed air, and then coat the entire valve mechanism and interior of the rocker box with clean engine oil.

(8) Variation in valve clearance not explained by normal wear. If there is excessive valve clearance, check for bent push rods. Replace any that are defective. Check also for valve sticking. If the push rod is straight and the valve opens and closes when the propeller is pulled through by hand, check the tightness of the adjusting screw to determine whether the clearance was set incorrectly or the adjusting screw has loosened.

After adjusting the clearance on each valve, tighten the lock screw or nut to the torque specified in the maintenance manual. After completing all clearance adjustments and before installing the rocker box covers, make a final check of all lock screws or nuts for tightness with a torque wrench.

Warped rocker box covers are a common cause of oil leakage. Therefore, the box covers should be checked for flatness at each valve inspection. Re-surface any warped covers by lapping them on emery cloth laid on a surface plate. Rocker box cover warpage is often caused by improper tightening of the rocker box cover nuts. Eliminate further warpage by torquing the nuts to the values specified in the manufacturer's service manual.

Valve Clearance

The amount of power that can be produced by a cylinder depends primarily on the amount of heat that can be produced in that cylinder without destructive effects on the cylinder components. Any condition that limits the amount of heat in the cylinder also limits the amount of power which that cylinder can produce.

The manufacturer, in determining valve timing and establishing the maximum power setting at which the engine will be permitted to run, considers the amount of heat at which cylinder components such as spark plugs and valves can operate efficiently. The heat level of the exhaust valve must be below that at which pitting and warping of the valve occurs.

The head of the exhaust valve is exposed to the heat of combustion at all times during the combustion period. In addition, the head of this valve and a portion of the stem are exposed to hot exhaust gases during the exhaust event. Under normal operation, the exhaust valve remains below the critical heat level because of its contact with the valve seat when closed and because of the heat dissipated through the stem. Any condition which prevents the valve from seating properly for the required proportion of time will cause the valve to exceed the critical heat limits during periods of high power output. In cases of extremely poor valve seat contact, the exhaust valve can warp during periods of low power output.

Normally, the exhaust valve is closed and in contact with its seat about 65% of the time during the four-stroke cycle. If the valve adjustment is correct, and if the valve seats firmly when closed, much of the heat is transferred from the valve, through the seat, into the cylinder head.

In order for a valve to seat, the valve must be in good condition, with no significant pressure being exerted against the end of the valve by the rocker arm. If the expansion of all parts of the engine including the valve train were the same, the problem of ensuring valve seating would be very easy to solve. Practically no free space would be necessary in the valve system. However, since there is a great difference in the amount of expansion of various parts of the engine, there is no way of providing a constant operating clearance in the valve train. The clearance in the valve-actuating system is very small when the engine is cold but is much greater when the engine is operating at normal temperature. The difference is caused by differences in the expansion characteristics of the various metals and by the differences in temperature of various engine parts.

There are many reasons why proper valve clearances are of vital importance to satisfactory and stable engine operation. For example, when the engine is operating, valve clearances establish valve timing. Since all cylinders receive their fuel/air mixture (or air) from a common supply, valve clearance affects both the amount and the richness or leanness of the fuel/air mixture. Therefore, it is essential that valve clearances be correct and uniform between each cylinder.

On radial engines, valve clearance decreases with a drop in temperature; therefore, insufficient clearance may cause the valve to hold open when extremely cold temperatures are encountered. This may make cold-weather starting of the engine difficult, if not impossible, because of the inability of the cylinders to pull a combustible charge into the combustion chamber.

Accurate valve adjustment establishes the intended valve seating velocity. If valve clearances are excessive, the valve seating velocity is too high. The result is valve pounding and stem stretching, either of which is conducive to valve failure. Insufficient clearance may make starting difficult and cause valves to stick in the "open" position, causing blow-by and subsequent valve failure as a result of the extreme temperatures to which the valve is subjected.

The engine manufacturer specifies the valve inspection period for each engine. In addition to the regular periods, inspect and adjust the valve mechanism any time there is rough engine operation, backfiring, loss of compression, or hard starting.

Because of variations in engine designs, various methods are required for setting valves to obtain correct and consistent clearances. In all cases, follow the exact procedure prescribed by the engine manufacturer, since obscure factors may be involved. For example, there is considerable cam float on many radial engines, and the valve-adjusting procedure for these engines is developed to permit accurate and consistent positioning of the cam. Since the ratio of valve movement to pushrod movement may be as much as two to one, each 0.001 in. shift of the cam can result in a 0.002 in. variation in valve clearances.

Wright engines incorporate pressure-lubricated valves. Oil under pressure passes through the pushrod and into the center of the valve-clearance adjusting screw. From this point, oil passages radiate in three directions. To permit proper lubrication, one of the three passages in the adjusting screw must be at least partially open to the passage leading to the rocker arm bearing. At the same time, neither of the other two passages must be uncovered by being in the slot in the rocker arm. Determine the location of the oil passages in the adjusting screw by locating the "0" stamped in three places on its top (figure 10–49). If there are only two stamped circles, the third oil passage is midway between the two marked ones. After final tailoring of the valve adjustment, if any one of the three oil passages aligns with or is closer than 3/32 in. to the nearest edge of the slot in the rocker arm, turn the adjusting screw in a direction to increase or decrease the clearance until the reference "0" mark is 3/32 in. from the nearest edge of the slot in the rocker arm, or until the maximum or minimum valve clearance is reached.

Pratt and Whitney engines also incorporate pressure-lubricated valves. On these engines, there is no slot in the rocker arm, but the valve-clearance adjusting screw can be turned in or backed out so far that the oil passage from the screw into the rocker arm is blocked. The specific instructions

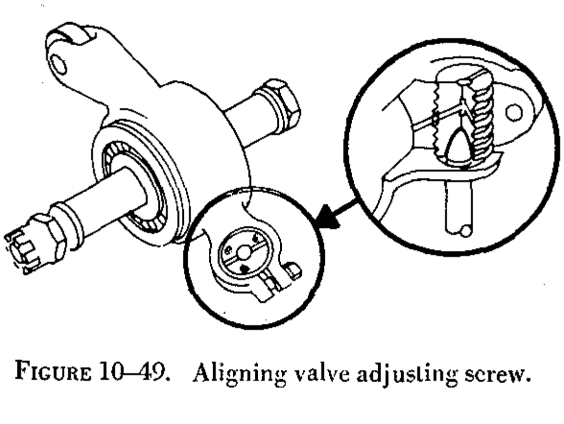


FIGURE 10–49. Aligning valve adjusting screw.

for setting clearance on the Pratt and Whitney engines state that a certain number of threads must show above the rocker arm. For example, on one model engine at least two threads and not more than five must show, and will, providing the pushrod is the correct length. Correct the pushrod length by pulling off one of the ball ends and changing the washer beneath for a thicker or thinner one. If there is no washer and the rod is too long, correct it by grinding away the end of the rod. Check the engine manufacturer's service or overhaul manual for the maximum or minimum number of threads which may show on the engine in question.

When adjusting valve clearances, always use the valve clearance gage or the dial gage specified in the "tools" section of the engine manufacturer's service manual. The specified gage is of the proper thickness and is so shaped that the end being used for checking can be slipped in a straight line between the valve and the rocker arm roller of the rocker arm. When a standard gage is used without being bent to the proper angle, a false clearance will be established since the gage will be cocked between the valve stem and rocker arm or rocker arm roller.

In making the check with the feeler gage, do not use excessive force to insert the gage between the valve stem and the adjustment screw or rocker arm roller. The gage can be inserted by heavy force, even though the clearance may be several thousandths of an inch less than the thickness of the gage. This precaution is particularly important on engines where the cam is centered during valve clearance adjustment, since forcing the gage on these engines may cause the cam to shift, with subsequent false readings.

When a dial gage and brackets for mounting the gage on the rocker box are specified, be sure to use them. A dial gage with a bracket may be used for checking valve clearances on any engine, provided the rocker arm arrangement is such that the pickup arm of the gage is located over the center line of the valve stem.

With a dial gage, the clearance is the amount of travel obtained when the rocker arm is rotated from the valve stem until the other end of the rocker arm contacts the pushrod.

Since valve clearance adjustment procedures vary between engines, a single treatment will not be sufficient. Thus, the procedures for various engines or groups of engines are treated separately in the following paragraphs. However, the procedures are described only to provide an understanding of the operations involved. Consult the engine manufacturer's instructions for the clearance to be set, the torque to be applied to lockscrews and rocker box cover nuts, and other pertinent details.

The first step in checking and adjusting valve clearances is to set the piston in the No. 1 cylinder at top-center compression stroke. Turn the propeller by hand until the valve action or cylinder pressure against a thumb held over the spark plug hole indicates that the piston is coming up on the compression stroke. Insert a piece of aluminum tubing into the spark plug hole and turn the propeller in the direction of rotation until the piston reaches its highest position. Proper precaution must be taken to make sure that the piston is on compression stroke.

After positioning the piston and crankshaft, adjust intake and exhaust valve clearances on the No. 1 cylinder to the prescribed values. Then adjust each succeeding cylinder in firing order, properly positioning the crankshaft for each cylinder.

Re-check the valve clearances and re-adjust any that are outside the limits. On this second check, align the oil passages in the adjusting screws of engines incorporating pressure-lubricated valves.

Adjusting Valves on R-2800 Engine

Establish top-center position of the No. 11 cylinder on the exhaust stroke. To do this, first ascertain that the piston is coming up on the compression stroke. Then insert an aluminum tube into the spark plug hole and turn the propeller in the direction of rotation until the piston has gone through the power stroke and returned to the top of the cylinder again. After the approximate top piston position has been ascertained, establish true top piston position by turning the propeller first in one direction and then in the other, until the position of the aluminum tube indicates the piston is at its highest point in the cylinder. A top-center indicator can also be used to establish top piston position.

Depress the intake valve on the No. 7 cylinder and the exhaust valve on the No. 15 cylinder, using a valve depressor tool. The valves must be depressed and released simultaneously and smoothly. These valves must be unloaded to remove the spring tension from the side positions on the cam and thus permit the cam to slide away from the valves to be adjusted until it contacts the cam bearing. This locates the cam in a definite position and prevents cam shift from introducing errors in clearance.

Adjust the intake valve on the No. 1 cylinder and the exhaust valve on the No. 3 cylinder. Follow the chart in figure 10–50 in adjusting the remaining valves.

Set Piston on Top Center Exhaust	Unload Valves on Cylinders		Check and Adjust Valves on Cylinders	
Cylinder Number	Intake	Exhaust	Intake	Exhaust
11	7	15	1	3
4	18	8	12	14
15	11	1	5	7
8	4	12	16	18
1	15	5	9	11
12	8	16	2	4
5	1	9	13	15
16	12	2	6	8
9	5	13	17	1
2	16	6	10	12
13	9	17	3	5
6	2	10	14	16
17	13	3	7	9
10	6	14	18	2
3	17	7	11	13
14	10	18	4	6
7	3	11	15	17
18	14	4	8	10

FIGURE 10–50. Valve clearance adjustment chart for R–2800 engine.

After completing the first check and adjustment of valve clearances, make a second check and re-adjust any clearances which vary from those specified in the engine manufacturer's service manual. On this second check, follow the precautions outlined in this chapter under adjustment of pressure-lubricated valves for Pratt and Whitney engines.

Adjusting Valves on R-1830 Engine

Establish compression stroke of the No. 1 cylinder by holding a thumb over the spark plug hole to feel cylinder compresion as the propeller is turned in the direction of rotation. When the pressure indicates that the piston is coming up on compression stroke, insert an aluminum tube into the spark plug hole and continue turning the propeller until the piston is at the top of its stroke.

With the crankshaft properly set, depress the intake valve on the No. 9 cylinder and the exhaust valve on the No. 7 cylinder with a valve depressor tool, and release them simultaneously. This operation relieves pressure on the sides of the cam and permits it to shift away from the valves in the No. 1 cylinder. The valves to be depressed are open at this time; thus. the ball end of the push rod will not fall out of position when the valves are depressed.

Adjust both intake and exhaust valves on the No. 1 cylinder. Check and adjust the valves on the remaining cylinders in firing order, following the chart in figure 10–51.

After completing this initial check, make a second check and re-adjust any clearances which are outside the limits specified in the engine manufacturer's maintenance manual. On this second check, follow the special precautions for adjustment of pressure-lubricated valves on Pratt and Whitney engines.

Adjusting Valves on 0-300, 0-335, 0-405, 0-425, V0-435 and 0-470 Engines

In checking and adjusting valve clearances on any of these engines, first set the piston in the No. 1 cylinder at top-center compression stroke. To find the right stroke, hold a thumb over the spark plug hole and turn the propeller in the direction of rotation until the pressure buildup indicates that the piston is coming up on compression stroke. Then insert an aluminum tube into the spark plug hole and continue turning the propeller until the piston is at the top of its stroke. Rock the propeller back and forth to aid in accurately positioning the piston.

After positioning the piston and crankshaft, displace the oil in the hydraulic tappet assembly by depressing the rocker arm with the tool specified in the engine manufacturer's service manual. Apply pressure smoothly and evenly since excessive force may damage the rocker arm or the push rod. Four or 5 seconds will be required to displace the oil

Set Piston on Top Center Compression	Unload Valves on Cylinders		Check and Adjust Valves on Cylinders
Cylinder Number	Intake	Exhaust	Intake and Exhaust
1	9	7	1
10	4	2	10
5	13	11	5
14	8	6	14
9	3	1	9
4	12	10	4
13	7	5	13
8	2	14	8
3	11	9	3
12	6	4	12
7	1	13	7
2	10	8	2
11	5	3	11
6	14	12	6

FIGURE 10–51. Valve clearance adjustment chart for R–1830 engine.

from the hydraulic tappet. If no clearance is obtained, remove and wash the tappet plunger and then re-check the clearance. Where valve adjustments are provided, re-adjust as necessary. On engines on which no adjustment is provided, replace the push rod with a longer or shorter rod, as outlined in the specific instructions for the engine.

Adjust the valves on succeeding cylinders in the engine firing order. After completing this initial check, make a second check and re-adjust any clearances which are outside the specified limits.

Valve Spring Replacement

A broken valve spring seldom affects engine operation and can, therefore, be detected only during careful inspection. Because multiple springs are used, one broken spring is hard to detect. But when a broken valve spring is discovered, it can be replaced without removing the cylinder. During valve spring replacement, the important precaution to remember is not to damage the spark plug hole threads. The complete procedure for valve spring replacement is as follows:

(1) Remove one spark plug from the cylinder.
(2) Turn the propeller in the direction of rotation until the piston is at the top of the compression stroke.
(3) Remove rocker arm.
(4) Using a valve spring compressor, compress the spring and remove the valve keepers. During this operation, it may be necessary to insert a piece of brass rod through the spark plug hole to decrease the space between the valve and the top of the piston head to break the spring retaining washer loose from the keepers. The piston, being at the top position on the compression stroke, prevents the valve from dropping down into the cylinder once the spring retaining washers are broken loose from the keepers on the stem.
(5) Remove the defective spring and any broken pieces from the rocker box.
(6) Install a new spring and correct washers. Then, using the valve spring compressor, compress the spring and, if necessary, move the valve up from the piston by means of a brass rod inserted through the spark plug hole.
(7) Re-install the keepers and rocker arms. Then check and adjust the valve clearance.
(8) Re-install the rocker box cover and the spark plug.

COLD CYLINDER CHECK

The cold cylinder check determines the operating characteristics of each cylinder of an air-cooled engine. The tendency for any cylinder or cylinders to be cold or to be only slightly warm indicates lack of combustion or incomplete combustion within the cylinder. This must be corrected if best operation and power conditions are to be obtained. The cold cylinder check is made with a cold cylinder indicator (Magic Wand). Engine difficulties which can be analyzed by use of the cold cylinder indicator (figure 10–52) are:

(1) Rough engine operation.
(2) Excessive r.p.m. drop during the ignition system check.
(3) High manifold pressure for a given engine r.p.m. during the ground check when the propeller is in the full low-pitch position.
(4) Faulty mixture ratios caused by improper valve clearance.

In preparation for the cold cylinder check, head

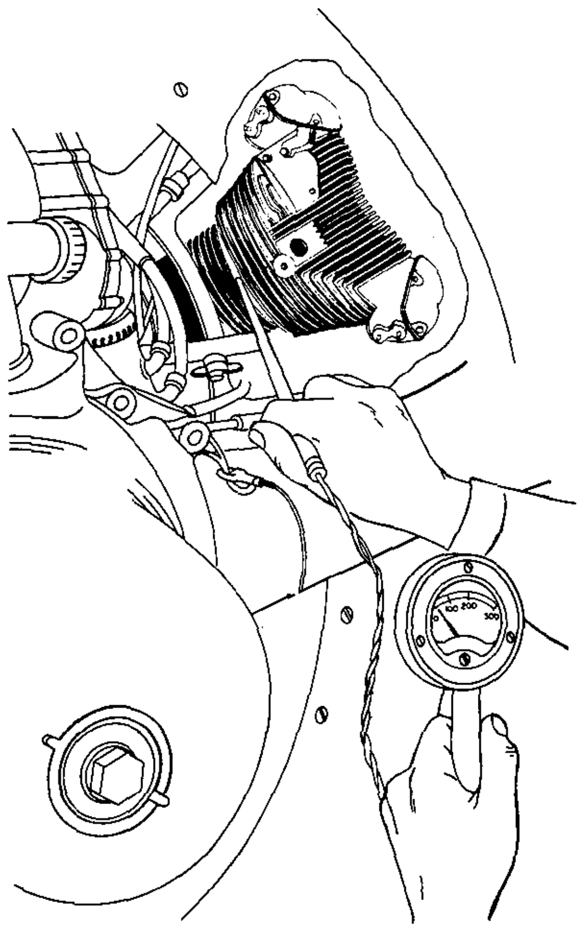


FIGURE 10–52. Using a cold cylinder indicator.

the aircraft into the wind to minimize irregular cooling of the individual cylinders and to ensure even propeller loading during engine operation.

Open the cowl flaps. Do not close the cowl flaps under any circumstances, as the resulting excessive heat radiation will affect the readings obtained and can damage the ignition leads.

Start the engine with the ignition switch in the "BOTH" position. After the engine is running, place the ignition switch in the position in which any excessive r.p.m. drop is obtained. When excessive r.p.m. drop is encountered on both right and left switch positions, or when excessive manifold pressure is obtained at a given engine r.p.m., perform the check twice, once on the left and once on the right switch position.

Operate the engine at its roughest speed between 1,200 and 1,600 r.p.m. until a cylinder head temperature reading of 150° to 170° C. (302° to 338° F.) is obtained, or until temperatures stabilize at a lower reading. If engine roughness is encountered at more than one speed, or if there is an indication that a cylinder ceases operating at idle or higher speeds, run the engine at each of these speeds and perform a cold cylinder check to pick out all the dead or intermittently operating cylinders. When low-power output or engine vibration is encountered at speeds above 1,600 r.p.m. when operating with the ignition switch on "BOTH," run the engine at the speed where the difficulty is encountered until the cylinder head temperatures are up to 150° to 170° C. or until the temperatures have stabilized at a lower value.

When cylinder head temperatures have reached the values prescribed in the foregoing paragraph, stop the engine by moving the mixture control to the idle cutoff or full lean position. When the engine ceases firing, turn off both ignition and master switches. Record the cylinder head temperature reading registered on the cockpit gage.

As soon as the propeller has ceased rotating, move a maintenance stand to the front of the engine. Connect the clip attached to the cold cylinder indicator lead to the engine or propeller to provide a ground for the instrument. Press the tip of the indicator pickup rod against each cylinder, and record the relative temperature of each cylinder. Start with number one and proceed in numerical order around the engine, as rapidly as possible. To obtain comparative temperature values, a firm contact must be made at the same relative location on each cylinder. Re-check any outstandingly low values. Also re-check the two cylinders having the highest readings to determine the amount of cylinder cooling during the test. Compare the temperature readings to determine which cylinders are dead or are operating intermittently.

Difficulties which may cause a cylinder to be inoperative (dead) on both right and left magneto positions are:

(1) Defective spark plugs.
(2) Incorrect valve clearances.
(3) Leaking impeller oil seal.
(4) Leaking intake pipes.
(5) Lack of compression.
(6) Plugged push rod housing drains.
(7) Faulty operation of the fuel-injection nozzle (on fuel-injection engines).

Before changing spark plugs or making an ignition harness test on cylinders that are not operating or are operating intermittently, check the magneto ground leads to determine that the wiring is connected correctly.

Repeat the cold cylinder test for the other magneto positions on the ignition switch, if necessary. Cooling the engine between tests is unnecessary. The airflow created by the propeller and the cooling effect of the incoming fuel/air mixture will be sufficient to cool any cylinders that are functioning on one test and not functioning on the next.

In interpreting the results of a cold cylinder check, remember that the temperatures are relative. A cylinder temperature taken alone means little, but when compared with the temperatures of other cylinders on the same engine, it provides valuable diagnostic information. The readings shown in figure 10–53 illustrate this point. On this check, the cylinder head temperature gage reading at the time the engine was shut down was 160° C. on both tests.

A review of these temperature readings reveals that, on the right magneto, cylinder number 6 runs cool and cylinders 8 and 9 run cold. This indicates that cylinder 6 is firing intermittently and cylinders 8 and 9 are dead during engine operation on the front plugs (fired by the right magneto). Cylinders 9 and 10 are dead during operation on the rear plugs (fired by the left magneto). Cylinder 9 is completely dead.

An ignition system operational check would not disclose this dead cylinder since the cylinder is inoperative on both right and left switch positions.

A dead cylinder can be detected during run-up, since an engine with a dead cylinder will require a

Cylinder No.	Right Magneto	Left Magneto
1	180	170
2	170	175
3	170	170
4	145	150
5	150	155
6	100	150
7	155	160
8	70	155
9	60	45
10	150	65
11	150	145
12	145	150
13	150	145
14	145	145

FIGURE 10–53. Readings taken during a cold-cylinder check.

higher-than-normal manifold pressure to produce any given r.p.m. below the cut-in speed of the propeller governor. A dead cylinder could also be detected by comparing power input and power output with the aid of a torquemeter.

Defects within the ignition system that can cause a cylinder to go completely dead are:

(1) Both spark plugs inoperative.

(2) Both ignition leads grounded, leaking, or open.

(3) A combination of inoperative spark plugs and defective ignition leads.

Faulty fuel-injection nozzles, incorrect valve clearances, and other defects outside the ignition system can also cause dead cylinders.

In interpreting the readings obtained on a cold-cylinder check, the amount the engine cools during the check must be considered. To determine the extent to which this factor should be considered in evaluating the readings, re-check some of the first cylinders tested and compare the final readings with those made at the start of the check. Another factor to be considered is the normal variation in temperature between cylinders and between rows. This variation results from those design features which affect the airflow past the cylinders.

TURBINE ENGINE MAINTENANCE

Turbine powerplant maintenance procedures vary widely according to the design and construction of the particular engine being serviced. The detailed procedures recommended by the engine manufacturer should be followed when performing inspections or maintenance.

Maintenance information presented in this section is not intended to specify the exact manner in which maintenance operations are to be performed, but is included to convey a general idea of the procedures involved. For the most part, the Pratt and Whitney JT3 turbojet engine is used in describing procedures for axial-flow compressor and turbine blade maintenance.

For inspection purpose, the turbine engine is divided into two main sections, the cold section and the hot section.

Compressor Section

Maintenance of the compressor, or cold section, is one of the concerns of the aviation mechanic. Damage to blades can cause engine failure and possible loss of costly aircraft. Much of the damage to the blades arises from foreign matter being drawn into the turbine engine air intakes.

The atmosphere near the ground is filled with tiny particles of dirt, oil, soot, and other foreign matter. A large volume of air is introduced into the compressor, and centrifugal force throws the dirt particles outward so that they build up to form a coating on the casing, the vanes, and the compressor blades.

Accumulation of dirt on the compressor blades reduces the aerodynamic efficiency of the blades with resultant deterioration in engine performance. The efficiency of the blades is impaired by dirt deposits in a manner similar to that of an aircraft wing under icing conditions. Unsatisfactory acceleration and high exhaust gas temperature can result from foreign deposits on compressor components.

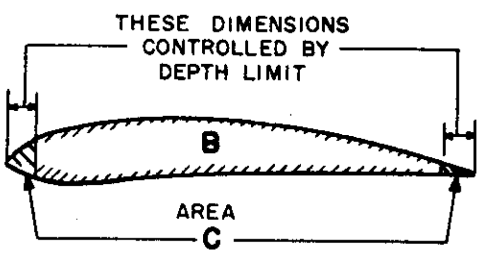
An end result of foreign particles, if allowed to accumulate in sufficient quantity, would be complete engine failure. The condition can be remedied by periodic inspection, cleaning, and repair of compressor components. This subject is treated in a general manner in this text because of the many different models of turbojet engines now in use in aviation.

Inspection and Cleaning

Minor damage to axial-flow engine compressor blades may be repaired if the damage can be removed without exceeding the allowable limits established by the manufacturer. Typical compressor blade repair limits are shown in figure 10–54. Well-rounded damage to leading and trailing edges that is evident on the opposite side of the blade is usually acceptable without re-work, provided the damage is in the outer half of the blade only and the indentation does not exceed values specified in

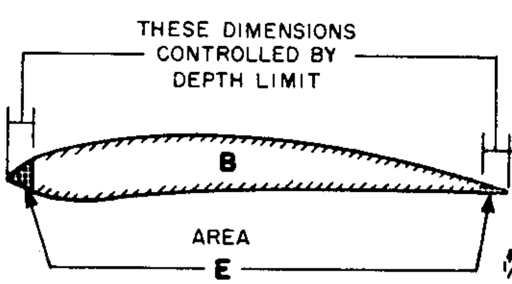
MAXIMUM ALLOWABLE REPAIR LIMITS— INCHES				
	STEEL BLADES		TITANIUM BLADES	
BLADE AREA	STAGES		STAGES	
	I through 4	5 through 9	I through 4	5 through 9
A	5/16 R	1/4 R	5/16 R	1/4 R
B	1/32 D	1/32 D	1/32 D	1/32 D
C	5/32 D	1/8 D	5/32 D	1/8 D
D	.008 D	.005 D	NONE	NONE
E	1/32 D	1/32 D	1/32 D	1/32 D

R — RADIUS D — DEPTH



CAUTION

THE LIMITS REFERRED TO IN THIS FIGURE IN AREAS "C" AND "E" PERTAIN TO LOCAL, ISOLATED, DAMAGED AREAS ONLY AND MUST NOT BE INTERPRETED AS AUTHORITY FOR REMOVAL OF MATERIAL ALL ACROSS THE TIP AND LEADING OR TRAILING EDGES AS MIGHT BE DONE IN A SINGLE MACHINING CUT.



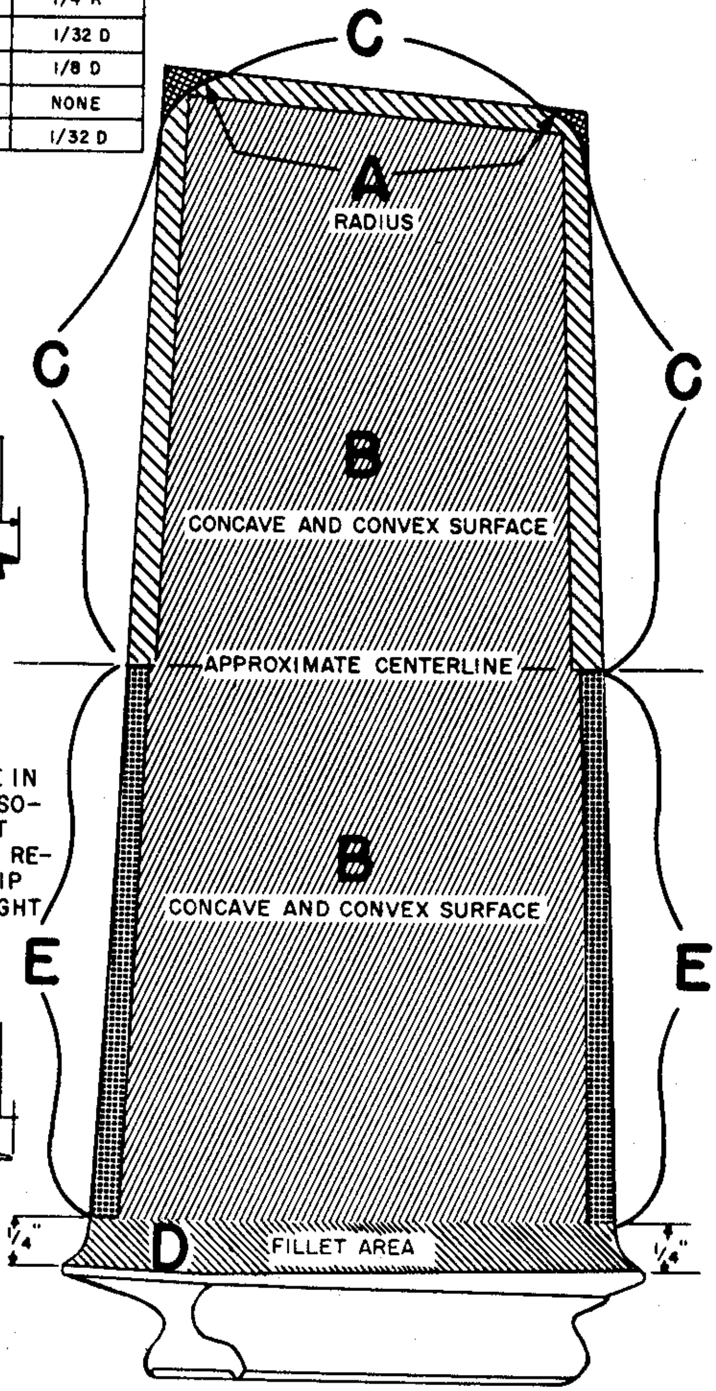


FIGURE 10–54. Typical compressor blade repair limits.

the engine manufacturer's service and overhaul instruction manuals.

When working on the inner half of the blade, damage must be treated with extreme caution. Repaired compressor blades are inspected by either magnetic particle or fluorescent penetrant inspection methods, or they are dye checked to ensure that all traces of the damage have been removed. All repairs must be well blended so that surfaces are smooth (figure 10–55). No cracks of any extent are tolerated in any area.

Whenever possible, stoning and local rework of the blade are performed parallel to the length of the blade. Rework must be accomplished by hand, using stones, files, or emery cloth. Do not use a power tool to buff the entire area of the blade. The surface finish in the repaired area must be comparable to that of a new blade.

On centrifugal flow engines, it is difficult to inspect the compressor inducers without first removing the air-inlet screen. After removing the screen, clean the compressor inducer and inspect it with a strong light. Check each vane for cracks by slowly turning the compressor.

Look for cracks in the leading edges. A crack is usually cause for engine replacement. The compressor inducers are normally the parts that are damaged by the impingement of foreign material during engine operation.

Compressor inducers are repaired by stoning out and blending the nicks and dents in the "critical band" (1-1/2 to 2-1/2 inches from the outside edge), if the depth of such nicks or dents does not exceed that specified in the engine manufacturer's service or overhaul instruction manuals. For nicks requiring repair, stone out material beyond the depth of damage to remove the resulting cold-worked metal. A generous radius must be applied at the edges of the blend. After blending the nick, it should be smoothed over with a crocus cloth. Pitting, nicks, or corrosion found on the sides of the inducer vanes are similarly removed by blending.

Causes of Blade Damage

Loose objects often enter an engine either accidentally or through carelessness. Items, such as pencils, handkerchiefs, and cigarette lighters, are often drawn into the engine. Do not carry any objects in shirt pockets when working around turbojet engines.

A compressor rotor can be damaged beyond repair by tools that are left in the air intake, where they are drawn into the engine on subsequent starts. A simple solution to the problem of tools being

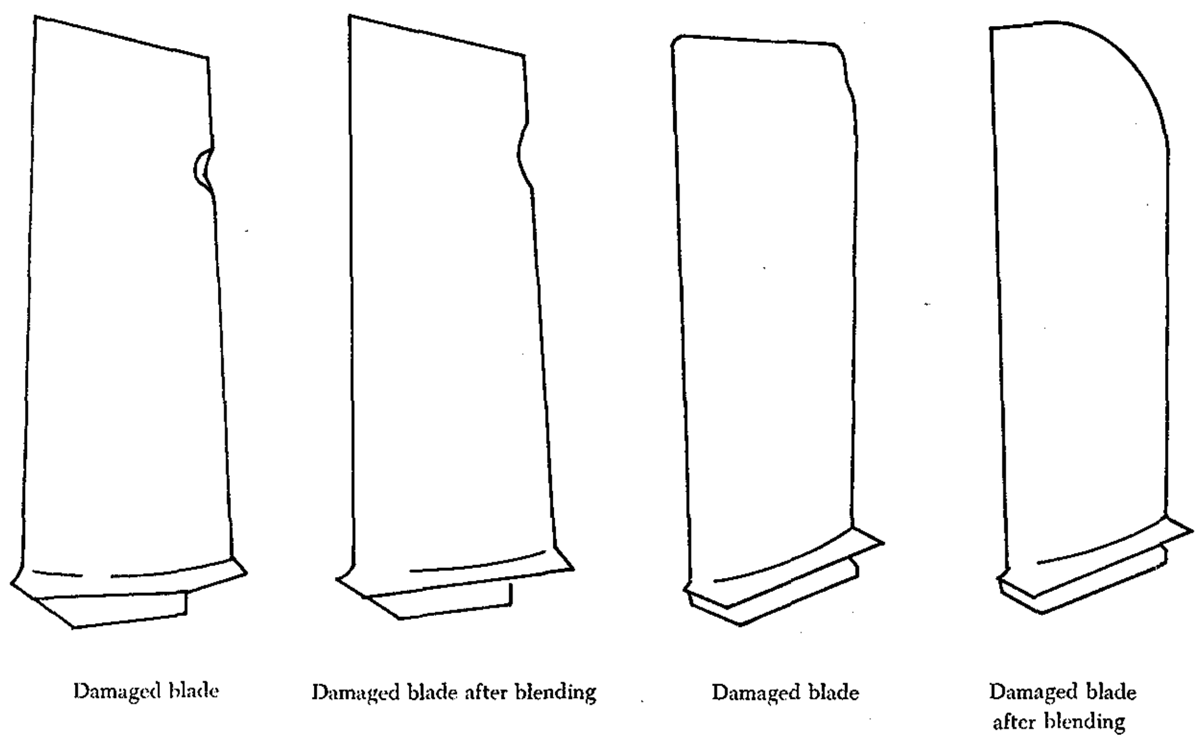


FIGURE 10–55. Compressor blade repair.

drawn into an engine is to check the tools against a tool checklist. Prior to starting a turbine engine, make a minute inspection of engine inlet ducts to assure that items such as nuts, bolts, lockwire, or tools were not left there after work had been performed.

Figure 10–56 shows some examples of blade damage to an axial-flow engine. The descriptions and possible causes of blade damage are given in table 11.

Corrosion pitting is not considered serious on the compressor stator vanes of axial-flow engines if the pitting is within the allowed tolerance.

Do not attempt to repair any vane by straightening, brazing, welding, or soldering. Crocus cloth, fine files, and stones are used to blend out damage by removing a minimum of material and leaving a surface finish comparable to that of a new part. The purpose of this blending is to minimize stresses that concentrate at dents, scratches, or cracks.

The inspection and repair of air intake guide vanes, swirl vanes, and screens on centrifugal-flow engines necessitates the use of a strong light. Inspect screen assemblies for breaks, rips, or holes. Screens may be tin-dipped to tighten the wire mesh, provided the wires are not worn too thin. If the frame strip or lugs have separated from the screen frames, re-brazing may be necessary.

Inspect the guide and swirl vanes for looseness. Inspect the outer edges of the guide vanes, paying particular attention to the point of contact between the guide and swirl vanes for cracks and dents due to the impingement of foreign particles; also inspect the edges of the swirl vanes. Inspect the downstream edge of the guide vanes very closely, because cracks are generally more prevalent in this area. Cracks which branch or fork out so that a piece of metal could break free and fall into the compressor are cause for vane rejection.

Blending and Replacement

Because of the thin-sheet construction of hollow vanes, blending on the concave and convex surfaces, including the leading edge, is limited. Small, shallow dents are acceptable if the damage is of a rounded or gradual contour type and not a sharp or V-type, and if no cracking or tearing of vane material is evident in the damaged area.

Trailing edge damage (figure 10–57) may be blended, if one-third of the weld seam remains after repair. Concave surfaces of rubber-filled vanes may have allowable cracks extending inward from the outer airfoil, provided there is no suggestion of pieces breaking away. Using a light and mirror, inspect each guide vane trailing edge and vane body for cracks or damage caused by foreign objects.

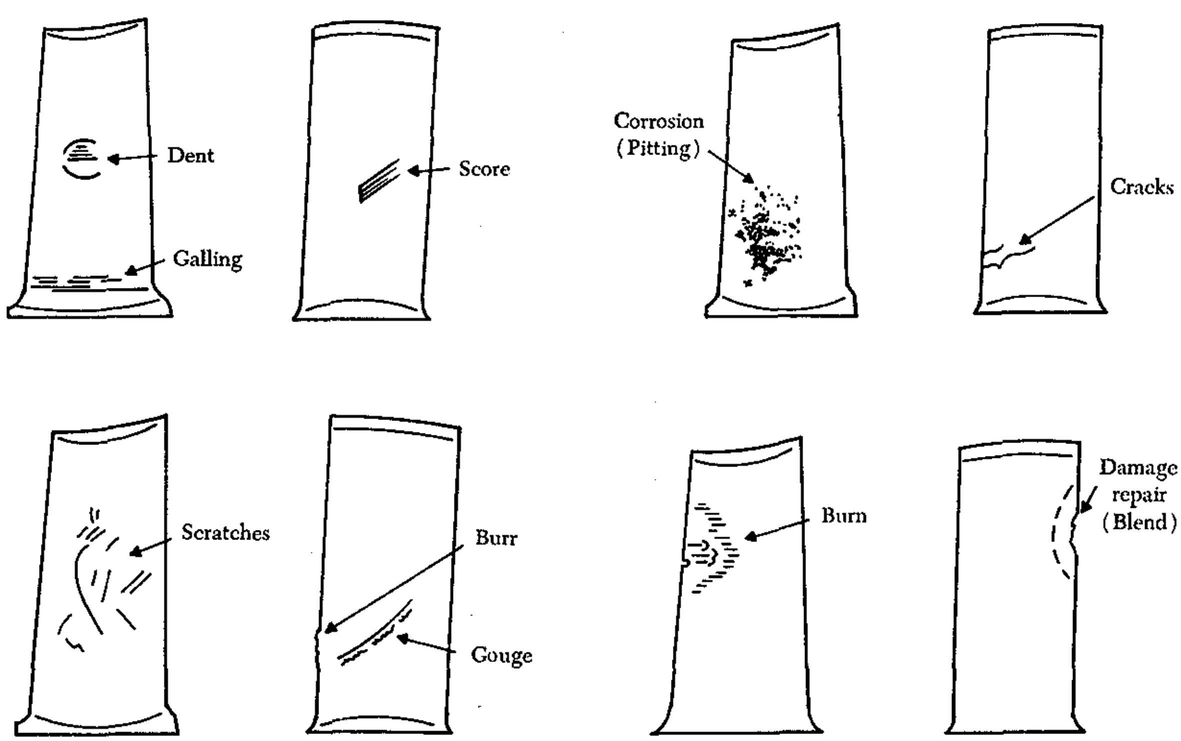


FIGURE 10–56. Compressor blade damage.

TABLE 11. Blade maintenance terms

Term	Appearance	Usual causes
Blend	Smooth repair of ragged edge or surface into the contour of surrounding area.	
Bow	Bent blade.	Foreign objects.
Burning	Damage to surfaces evidenced by discoloration or, in severe cases, by flow of material.	Excessive heat.
Burr	A ragged or turned out edge.	Grinding or cutting operation.
Corrosion (pits)	Breakdown of the surface; pitted appearance.	Corrosive agents—moisture, etc.
Cracks	A partial fracture (separation).	Excessive stress due to shock, overloading, or faulty processing; defective materials; overheating.
Dent	Small, smoothly rounded hollow.	Striking of a part with a dull object.
Gall	A transfer of metal from one surface to another.	Severe rubbing.
Gouging	Displacement of material from a surface; a cutting or tearing effect.	Presence of a comparatively large foreign body between moving parts.
Growth	Elongation of blade.	Continued and/or excessive heat and centrifugal force.
Pit	(See Corrosion.)	
Profile	Contour of a blade or surface.	
Score	Deep scratches.	Presence of chips between surfaces.
Scratch	Narrow shallow marks.	Sand or fine foreign particles; careless handling.

COMBUSTION SECTION

One of the controlling factors in the service life of the turbine engine is the inspection and cleaning of the hot section. Too much emphasis cannot be placed on the importance of careful inspection and repair of this section. One of the most frequent discrepancies that will be detected while inspecting the hot section of a turbine engine is cracking. These cracks may occur in many forms, and the only way to determine that they are within acceptable limits is to refer to the applicable engine manufacturer's service and overhaul manuals.

Cleaning the hot section is not usually necessary for a repair in the field. However, if it becomes necessary to disassemble the engine, a correct and thorough cleaning is of the greatest importance to a successful inspection and repair.

Engine parts can be degreased by using the emulsion-type cleaners or chlorinated solvents. The emulsion-type cleaners are safe for all metals, since they are neutral and noncorrosive. Cleaning parts by the chlorinated solvent method leaves the parts absolutely dry; if they are not to be subjected to further cleaning operations, they should be sprayed with a corrosion-preventive solution to protect them against rust or corrosion.

The extent of disassembly is to open the combustion case for the inspection of the hot section. However, in performing this disassembly, numerous associated parts will be readily accessible for inspection.

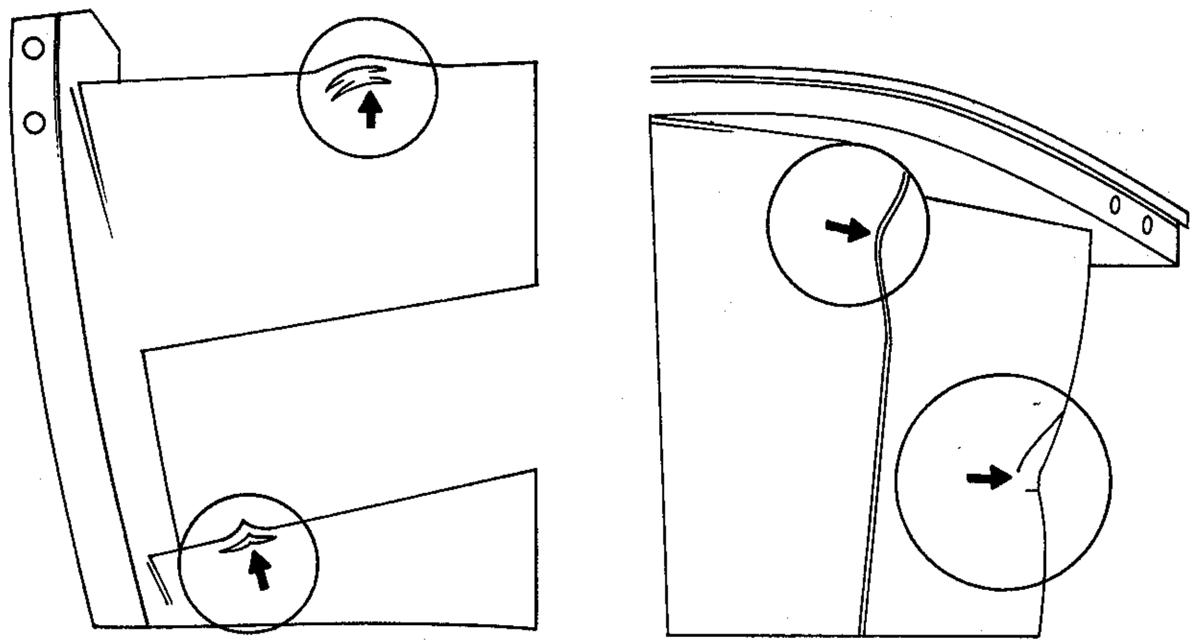
The importance of properly supporting the engine and the parts being removed cannot be overstressed. The alignment of parts being removed and installed is also of the utmost importance.

After all repairs are made, the manufacturer's detailed assembly instructions should be followed. These instructions are important in efficient engine maintenance, and the ultimate life and performance of the engine can be seriously affected if they are slighted through carelessness or neglect.

Extreme care must be taken to prevent dirt, dust, cotter pins, lockwire, nuts, washers, or other foreign material from entering the engine. If, at any time, such pieces are dropped, the assembly of the engine must stop until the dropped article is located, even though this may require a considerable amount of disassembly.

Marking Materials for Combustion Section Parts

Certain materials may be used for temporary marking during assembly and disassembly. Layout dye (lightly applied) or chalk may be used to mark parts that are directly exposed to the engine's gas path, such as turbine blades and disks, turbine vanes, and combustion chamber liners. A wax marking pencil may be used for parts that are not



Before blending

After blending

FIGURE 10–57. Guide vane trailing edge damage.

directly exposed to the gas path. Do not use a wax marking pencil on a liner surface or a turbine rotor.

The use of carbon alloy or metallic pencils is not recommended because of the possibility of causing intergranular attack, which could result in a reduction in material strength.

Combustion Section Inspection

The following are general procedures for performing a hot section (turbine and combustion section) inspection. It is not intended to imply that these procedures are to be followed when performing repairs or inspections on turbine engines. However, the various practices are typical of those used on many turbine engines. Where a clearance or tolerance is shown it is for illustrative purposes only. Always follow the instructions contained in the applicable manufacturer's maintenance and overhaul manuals.

The entire external combustion case should be inspected for evidence of hotspots, exhaust leaks, and distortions before the case is opened. After the combustion case has been opened, the combustion chambers can be inspected for localized overheating, cracks, or excessive wear. Inspect the first-stage turbine blades and nozzle guide vanes for cracks, warping, or foreign object damage. Also inspect the combustion chamber outlet ducts and turbine nozzle for cracks and for evidence of foreign object damage.

Inspection and Repair of Combustion Chambers and Covers

Inspect the combustion chambers and covers for cracks by using dye penetrant or the fluorescent penetrant inspection method. Any cracks, nicks, or dents in the cover are usually cause for rejection. Inspect the covers, noting particularly the area around the fuel drain bosses for any pits or corrosion.

Inspect the interior of the combustion liners for excess weld material expelled from the circumferentially welded seams. To prevent future damage to the turbine blades, remove weld material or slag that is not thoroughly fused to the base material of the combustion liner.

When repairing the combustion chamber liner, the procedures given in the appropriate engine manufacturer's overhaul instruction manual should be followed. If there is doubt that the liner is serviceable, it should be replaced.

Acceptance Standards for Combustion Chamber Liners

The combustion chamber liner is inspected to determine the serviceability of liner weldments that have deteriorated from engine operation. Limitations on such deterioration are based on the requirement that the combustion chambers must give satisfactory service during the period of operation between successive inspections of the parts.

Certain types of cracking and burning deterioration resulting from thermal stresses may be found after periods of operation. However, the progress of such discrepancies with further operation is usually negligible, since the deterioration produced by thermal stresses, in effect, relieves the original stress condition.

Usually, a given type of deterioration will recur from chamber to chamber in a given engine.

Current manufacturer's service and overhaul manuals should be consulted for allowable limits of cracks and damage. The following paragraphs describe some typical discrepancies found on combustion chambers. Figure 10–58 shows a combustion chamber liner with the components listed to help locate discrepancies.

When considering the acceptability of a suspected liner, the aim must be to prevent the breakaway of an unsupported area of metal such as that lying in the fork of a crack or between two cracks radiating from the same airhole. Single cracks are acceptable in most cases, provided they do not cause mechanical weakness that could lead to further failure.

Combustion Chamber Cracks

Combustion chambers should be replaced or repaired if two cracks are progressing from a free edge so that their meeting is imminent and could allow a piece of metal (that could cause turbine damage) to break loose..

Separate cracks in the baffle are acceptable. Baffle cracks connecting more than two holes should be repaired.

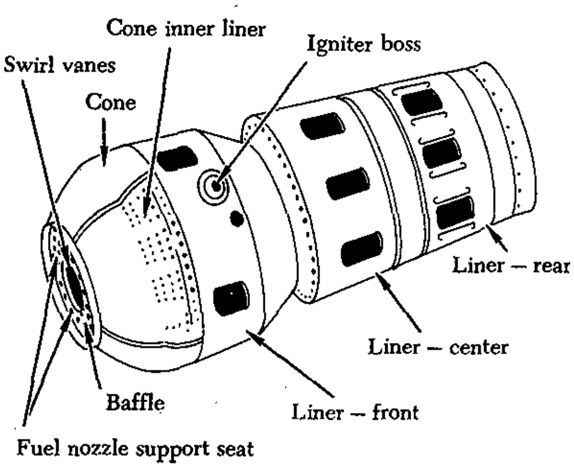


FIGURE 10–58. Combustion chamber liner nomenclature.

Cracks in the cone are rare but, at any location on this component, are cause for rejection of the liner.

Cracks in the swirl vanes are cause for rejection of the liner. Loose swirl vanes may be repaired by silver brazing.

Cracks in the front liner emanating from the airholes are acceptable, provided they do not exceed allowable limits. If such cracks fork or link with others, the liner must be repaired. If two cracks originating from the same airhole are diametrically opposite, the liner is acceptable.

Radial cracks extending from the interconnector and spark-igniter boss are acceptable if they do not exceed allowable limits and if such cracks do not fork or link with others. Circumferential cracks around the boss pads should be repaired prior to re-use of the liner.

After long periods of engine operation, the external surfaces of the combustion chamber liner location pads will often show signs of fretting. This is acceptable, provided no resultant cracks or perforation of the metal is apparent.

Any cover or chamber inadvertently dropped on a hard surface or mishandled should be thoroughly inspected for minute cracks which may elongate over a period of time and then open, creating a hazard.

Burned or Buckled Areas

Parts may be found wherein localized areas have been heated to an extent to buckle small portions of the chamber. Such parts are considered acceptable if the burning of the part has not progressed into an adjacent welded area or to such an extent as to weaken the structure of the liner weldment. Buckling of the combustion chamber liner can be corrected by straightening the liner.

Moderate buckling and associated cracks are acceptable in the row of cooling holes. More severe buckling that produces a pronounced shortening or tilting of the liner is cause for rejection.

Upon completion of the repairs by welding, the liner should be restored as closely as possible to its original shape. This usually can be accomplished by using ordinary sheetmetal-forming hand dollies and hammers available at most metal working and welding shops.

Fuel Nozzle and Support Assemblies

Clean all carbon deposits from the nozzles by washing with a cleaning fluid approved by the engine manufacturer and remove the softened deposits with a soft bristle brush or small piece of wood. It is desirable to have filtered air passing through the nozzle during the cleaning operation to carry away deposits as they are loosened. Make sure all parts are clean. Dry the assemblies with clean, filtered air.

Because the spray characteristics of the nozzle may become impaired, no attempt should be made to clean the nozzles by scraping with a hard implement or by rubbing with a wire brush.

Inspect each component part of the fuel nozzle assembly for nicks and burrs.

INSPECTION AND REPAIR OF TURBINE DISK

Turbine Disk Inspection

The inspection for cracks is of the utmost importance. Crack detection, when dealing with the turbine disk and blades, is practically all visual. The material of which the disk and blades are made does not lend itself freely to crack detection fluids; therefore, they should be scrutinized most carefully under at least a 9- to 12-power magnifying glass. Any questionable areas call for more minute inspection. Cracks, on the disk, however minute, necessitate the rejection of the disk and replacement of the turbine rotor. Slight pitting caused by the impingement of foreign matter may be blended by stoning and polishing.

Turbine Blade Inspection

Turbine blades are usually inspected and cleaned in the same manner as compressor blades. However, because of the extreme heat under which the turbine blades operate, they are more susceptible to damage. Using a strong light and a magnifying glass, inspect the turbine blades for stress rupture cracks (figure 10–59) and deformation of the leading edge (figure 10–60).

Stress rupture cracks usually appear as minute hairline cracks on or across the leading or trailing edge at a right angle to the edge length. Visible cracks may range in length from one-sixteenth inch upward. Deformation, caused by over-temperature, may appear as waviness and/or areas of varying airfoil thickness along the leading edge. The leading edge must be straight and of uniform thickness along its entire length, except for areas repaired by blending.

Do not confuse stress rupture cracks or deformation of the leading edge with foreign material impingement damage or with blending repairs to the blade. When any stress rupture cracks or deformation of the leading edges of the first-stage turbine

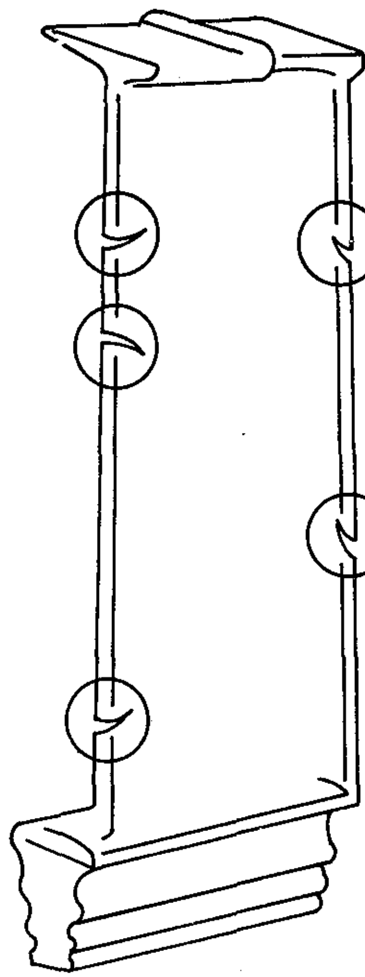


FIGURE 10–59. Stress rupture cracks.

blades are found, an over-temperature condition must be suspected. Check the individual blades for stretch and the turbine disk for hardness and stretch.

Blades removed for a detailed inspection or for a check of turbine disk stretch must be re-installed in the same slots from which they were removed. Number the blades prior to removal.

The turbine blade outer shroud should be inspected for air seal wear. If shroud wear is found, measure the thickness of the shroud at the worn area. Use a micrometer or another suitable and accurate measuring device that will ensure a good reading in the bottom of the comparatively narrow wear groove. If the remaining radial thickness of the shroud is less than that specified, the stretched blade must be replaced.

Typical blade inspection requirements are indicated in figure 10–61. Blade tip curling within a one-half-inch square area on the leading edge of the blade tip is usually acceptable if the curling is not

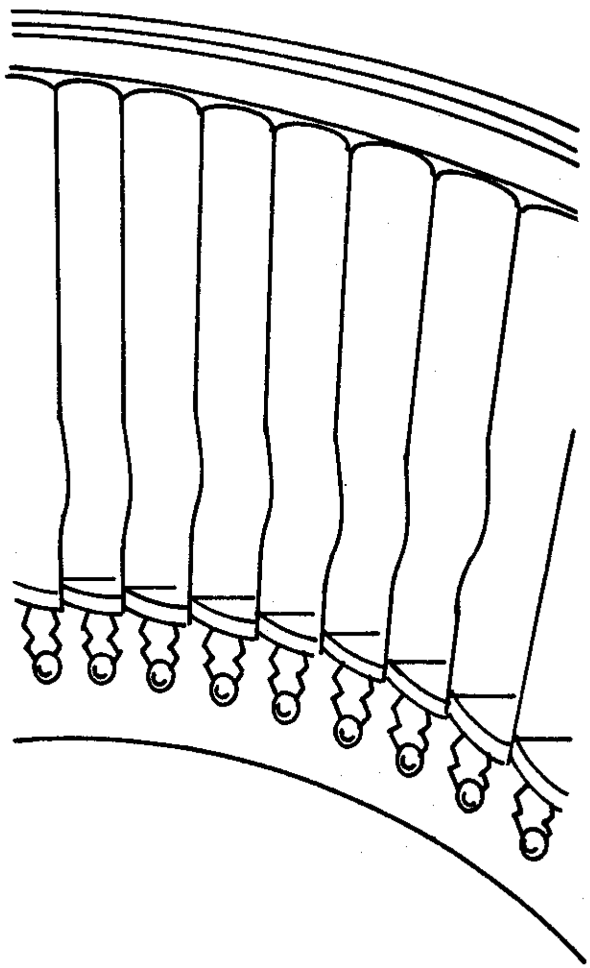


FIGURE 10–60. Turbine blade waviness.

sharp. Curling is acceptable on the trailing edge if it does not extend beyond the allowable area. Any sharp bends that may result in cracking or a piece breaking out of the turbine blade is cause for rejection, even though the curl may be within the allowable limits. Each turbine blade should be inspected for cracks.

Turbine Blade Replacement Procedure

Turbine blades are generally replaceable, subject to moment-weight limitations. These limitations are contained in the engine manufacturer's applicable technical instructions.

If visual inspection of the turbine assembly discloses several broken, cracked, or eroded blades, replacing the entire turbine assembly may be more economical than replacing the damaged blades.

A typical disk and blade assembly is illustrated in figure 10–62. In the initial buildup of the turbine, a complete set of 54 blades made in coded pairs (two blades having the same code letters), is laid out on a bench in the order of diminishing moment-weight. The code letters indicating the moment-weight balance in ounces are marked on the rear face of the fir-tree section of the blade (viewing the blade as installed at final assembly of the engine). The pair of blades having the heaviest moment-weight is numbered 1 and 28; the next heaviest pair of blades is numbered 2 and 29; the third heaviest pair is numbered 3 and 30. This is continued until all the blades have been numbered.

Mark a number 1 on the face of the hub on the turbine disk. The No. 1 blade is then installed adjacent to the number 1 on the disk (figure 10–63). The remaining blades are then installed consecutively in a clockwise direction, viewed from the rear face of the turbine disk. If there are several pairs of blades having the same code letters, they are installed consecutively before going to the next code letters.

If a blade requires replacement, the diametrically opposite blade must also be replaced. The blades used as replacements must be of the same code, but do not have to be of the same code as the blades removed. The maximum number of blades that may be replaced in the field varies between make and model of engines and is established by the engine manufacturer.

To replace a blade, or any number of blades, of a turbine disk and blade assembly, the procedures in the following paragraphs are given as an example.

Bend up the tab of each tab lock; then drive out the blade, knocking it toward the front of the turbine disk, using a brass drift and a hammer. Withdraw and discard the turbine blade locks from the blades.

Insert a new blade with the tab blade toward the front of the disk; then, while holding the tab against the disk, check the clearance between the blade shoulder and the turbine disk. It may be necessary to grind material from the shoulder of the blade to bring the clearance within limits (figure 10–64). Refer to the Table of Limits in the engine manufacturer's overhaul manual for the clearances concerning the turbine blades.

While holding the blade in the direction of rotation (counterclockwise), check the clearance between the blade shoulder tips and those of the adjacent blades (figure 10–64). If the clearance is insufficient, remove the blade and grind material from the tips to bring the clearance within limits. Using a

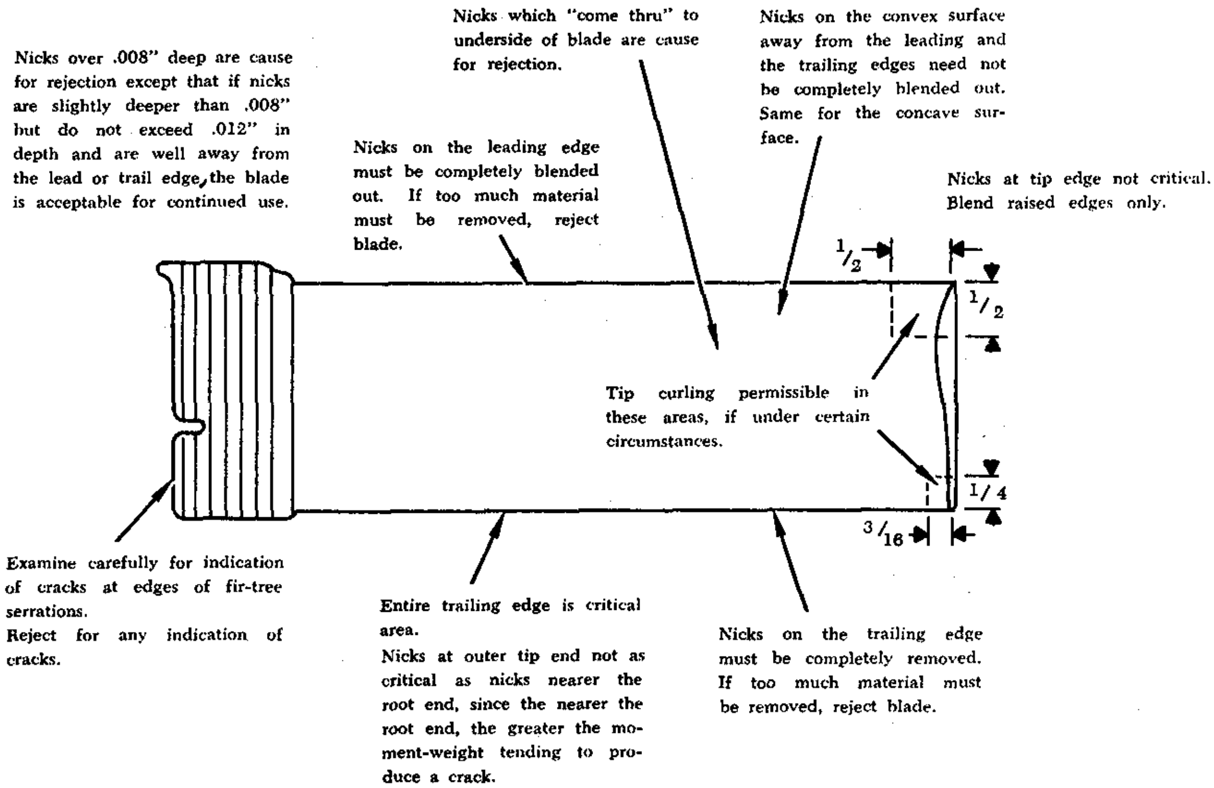


FIGURE 10–61. Typical turbine blade inspection.

dial indicator, check the blade tip radial movement while holding the blade tab against the disk.

Place a new lock in the turbine blade; then install the blade in its correct position in the turbine disk. Position the turbine so that the blade is over a peening plate, an anvil, or other suitable support. Using a starting punch, peen the tab of the lock in an inward direction. Finish peening the lock, using a finishing punch to obtain the allowable maximum axial end play. Examine the peened lock for evidence of cracking, using a 3- to 5-power glass. If it is cracked, remove the blade and install a new lock until a satisfactory installation is accomplished.

Turbine Nozzle Vane Inspection

After opening the combustion chambers and removing the combustion liners, the first-stage turbine blades and turbine nozzle vanes are accessible for inspection. The blade limits specified in the engine manufacturer's overhaul and service instruction manual should be adhered to. Figure 10–65 shows where cracks usually occur on a turbine nozzle assembly. Slight nicks and dents are permissible if the depth of damage is within limits.

Inspect the turbine nozzle vanes for bowing, measuring the amount of bowing on the trailing edge of each vane. Bowed nozzle vanes may be an indication of a malfunctioning fuel nozzle. Reject vanes which are bowed more than the allowable amount. Bowing is always greater on the trailing edge; thus if this edge is within limits, the leading edge is also acceptable.

Inspect the nozzle vanes for nicks or cracks. Small nicks are not cause for vane rejection, provided such nicks blend out smoothly.

Inspect the nozzle vane supports for defects caused by the impingement of foreign particles. Use a stone to blend any doubtful nicks to a smooth radius.

Like turbine blades, it is possible to replace a maximum number of turbine nozzle vanes in some engines. If more than this number of vanes are damaged, a new turbine nozzle vane assembly must be installed.

With the tailpipe removed, the rear turbine stage can be inspected for any cracks or evidence of blade stretch. The rear-stage nozzle can also be inspected with a strong light by looking through the rear-stage turbine.

Clearances

Checking the clearances is one of the procedures in the maintenance of the turbine section of a

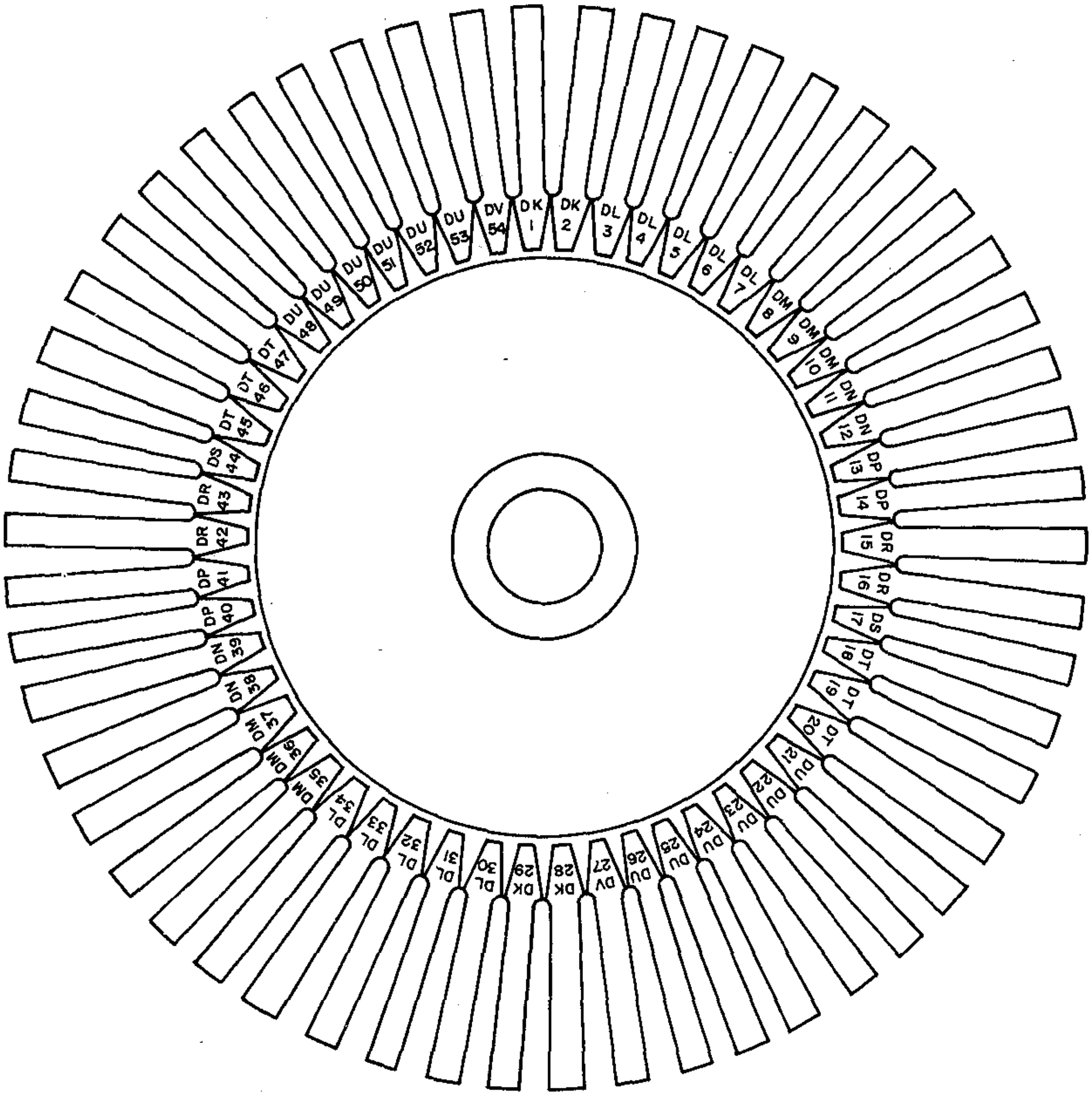


FIGURE 10–62. Typical turbine rotor blade moment-weight distribution.

turbine engine. The manufacturer's service and overhaul manual gives the procedures and tolerances for checking the turbine. Figures 10–66 and 10–67 show clearances being measured at various locations. To obtain accurate readings, special tools provided by each manufacturer must be used as described in the service instructions for specific engines.

Exhaust Section

The exhaust section of the turbojet engine is susceptible to heat cracking. This section must be thoroughly inspected along with the inspection of the combustion section and turbine section of the engine. Inspect the exhaust cone and tailpipe for cracks, warping, buckling, or hotspots. Hotspots on the tail cone are a good indication of a malfunctioning fuel nozzle or combustion chamber.

The inspection and repair procedures for the hot section of any one gas turbine engine are similar to those of other gas turbine engines. One usual difference is the nomenclature applied to the various parts of the hot section by the different manufacturers. Other differences include the manner of disassembly, the tooling necessary, and the repair methods and limits.

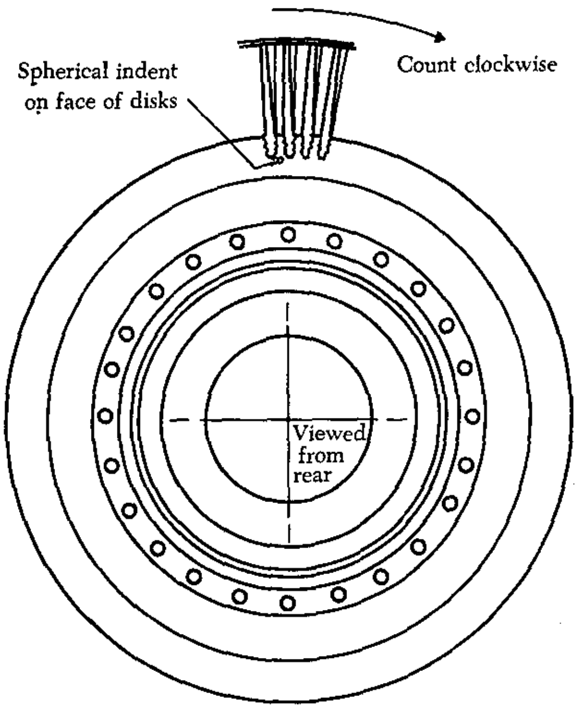
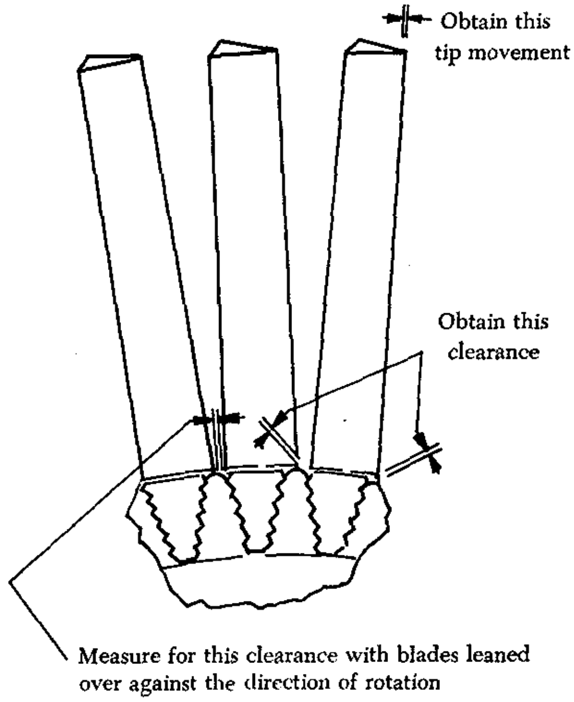


FIGURE 10–63. Turbine blades.



Rear view of turbine blades

FIGURE 10–64. Turbine blade replacement clearances.

COMMERCIAL RATINGS

An understanding of gas turbine engine ratings is necessary to use intelligently the engine operating curves contained in the aircraft and engine maintenance manuals. The ratings for commercial engines are defined by the SAE (Society of Automotive Engineers).

Takeoff (wet). This is the maximum allowable thrust for takeoff. The rating is obtained by actuating the water-injection system and setting the computed "wet" thrust with the throttle, in terms of a predetermined turbine discharge pressure or engine pressure ratio for the prevailing ambient conditions. The rating is restricted to takeoff, is time-limited, and will have an altitude limitation. Engines without water injection do not have this rating.

Takeoff (dry). This is the maximum allowable thrust without the use of water injection. The rating is obtained by adjusting the throttle to the takeoff (dry) thrust for the existing ambient conditions, in terms of a predetermined turbine discharge pressure or engine pressure ratio. The rating is time-limited and is to be used for takeoff only.

Maximum continuous. This rating is the maximum thrust which may be used continuously and is intended only for emergency use at the discretion of the pilot. The rating is obtained by adjusting the throttle to a predetermined turbine discharge pressure or engine pressure ratio.

Normal rated. Normal rated thrust is the maximum thrust approved for normal climb. The rating is obtained in the same manner as maximum continuous. Maximum continuous thrust and normal rated thrust are the same on some engines.

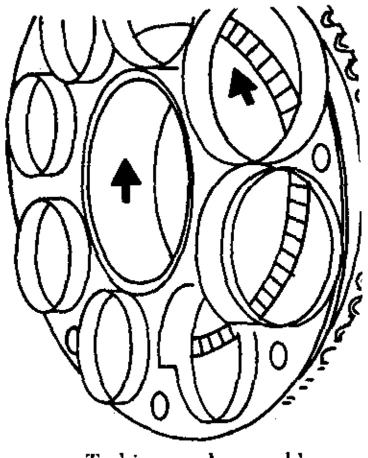
Maximum cruise. This is the maximum thrust approved for cruising. It is obtained in the same manner as maximum continuous.

Idle. This is not an engine rating, but rather a throttle position suitable for minimum thrust operation on the ground or in flight. It is obtained by placing the throttle in the idle detent on the throttle quadrant.

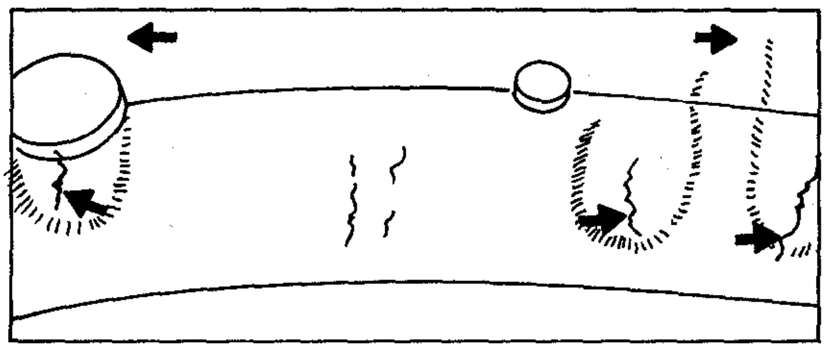
ENGINE INSTRUMENTATION

Although engine installations may differ, depending upon the type of both the aircraft and the engine, gas turbine engine operation is usually controlled by observing the instruments discussed in the following paragraphs.

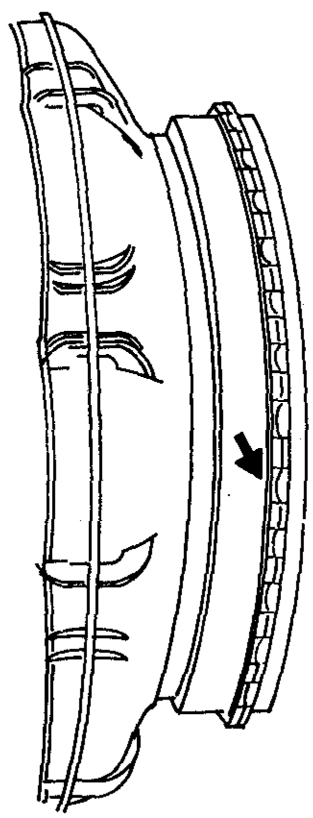
Engine thrust is indicated by either a turbine pressure indicator or an engine pressure ratio indicator, depending upon the installation. Both types of pressure instruments are discussed here because

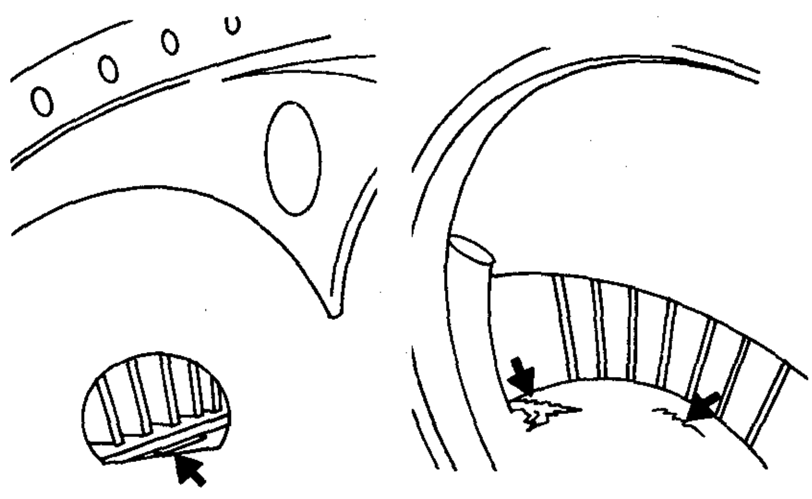


Turbine nozzle assembly.

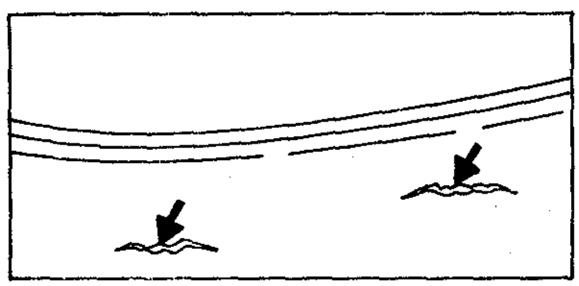


Turbine nozzle assembly at junction of combustion chamber outlet duct and turbine nozzle outer case.





Cracked area along spot weld line on inner duct.



Spot weld cracks on inner duct.

FIGURE 10–65. Typical turbine nozzle assembly defects.

either indicator may be used. Of the two, the turbine discharge pressure indicator is usually more accurate, primarily because of its simplicity of construction. It may be installed on the aircraft permanently or, in some instances temporarily, such as during an engine trim. An engine pressure ratio indicator, on the other hand, is less complex to use because it compensates automatically for the effects of airspeed and altitude factors by considering compressor inlet pressure.

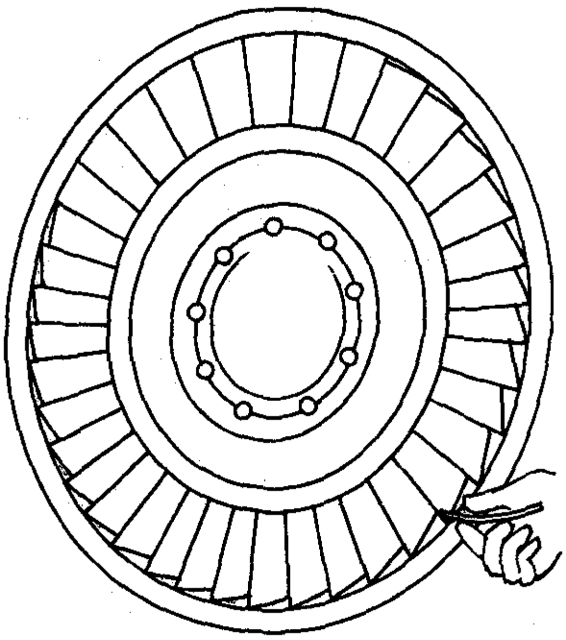


FIGURE 10–66. Measuring the turbine blades to shroud (tip) clearances.

Turbine Discharge Pressure Indicator

This instrument not only indicates the total engine internal pressure immediately aft of the last turbine stage, but also indicates the pressure available to generate thrust, when used with compressor inlet pressure.

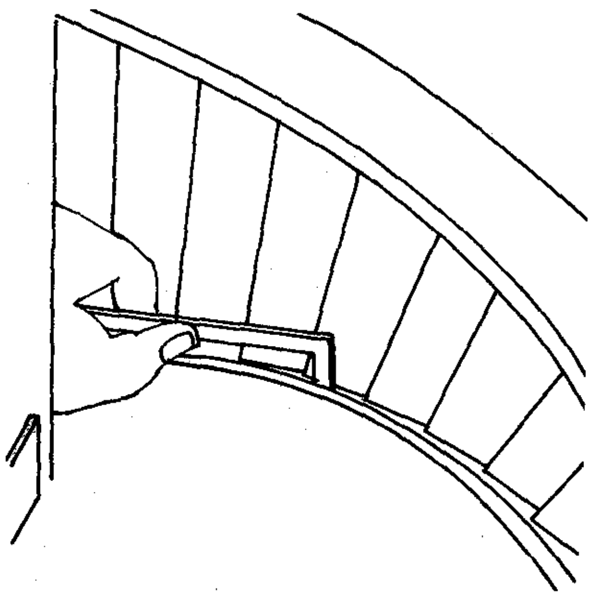


FIGURE 10–67. Measuring turbine wheel to exhaust cone clearance.

Engine Pressure Ratio Indicator

EPR (engine pressure ratio) is an indication of the thrust being developed by the engine. It is instrumented by total pressure pickups in the engine inlet and in the turbine exhaust. The reading is displayed in the cockpit by the EPR gage, which is used in making engine power settings. Figure 10–68 illustrates a turbine discharge pressure indicator (A) and an EPR gage (B).

Torquemeter (Turboprop Engines)

Because only a small part of the propulsive force is derived from the jet thrust, neither turbine discharge pressure nor engine pressure ratio is used as an indicator of the power produced by a turboprop engine. Turboprops are usually fitted with a torquemeter. The torquemeter (figure 10–69) can be operated by a torquemeter ring gear in the engine nose section similar to that provided on large

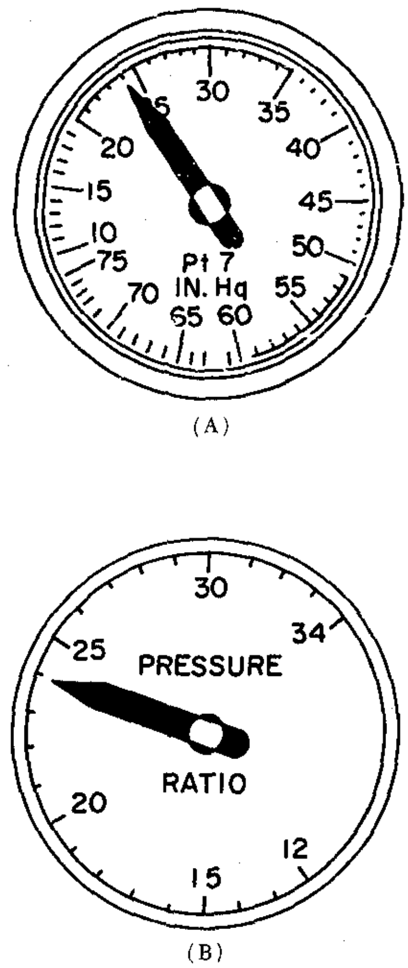


FIGURE 10–68. (A) Turbine discharge pressure, and (B) engine pressure ratio indicators.

reciprocating engines or by pick-ups on a torque shaft. The torque being developed by the engine is proportional to the horsepower, and is used to indicate shaft horsepower.

Tachometer

Gas turbine engine speed is measured by the compressor r.p.m., which will also be the turbine r.p.m. Tachometers (figure 10–69) are usually calibrated in percent r.p.m. so that various types of engines can be operated on the same basis of comparison. As previously noted, compressor r.p.m. on centrifugal-compressor turbojet engines is a direct indication of the engine thrust being produced. For axial-compressor engines, the principal purpose of the tachometer is to monitor r.p.m. during an engine start and to indicate an overspeed condition, if one occurs.

Exhaust Gas Temperature Indicator

EGT (exhaust gas temperature), TIT (turbine inlet temperature), tailpipe temperature, and turbine discharge temperature are one and the same. Temperature is an engine operating limit and is used to monitor the mechanical integrity of the turbines, as well as to check engine operating conditions. Actually, the turbine inlet temperature is the important consideration, since it is the most critical of all the engine variables. However, it is impractical to measure turbine inlet temperature in most engines, especially large models. Consequently, temperature thermocouples are inserted at the turbine discharge, where the temperature provides a relative indication of that at the inlet. Although the temperature at this point is much lower than at the inlet, it provides surveillance over the engine's internal operating conditions. Several thermocouples are usually used, which are spaced at intervals around the perimeter of the engine exhaust duct near the turbine exit. The EGT indicator (figure 10–69) in the cockpit shows the average temperature measured by the individual thermocouples.

Fuel-Flow Indicator

Fuel-flow instruments indicate the fuel flow in lbs./hr. from the engine fuel control. Fuel flow is of interest in monitoring fuel consumption and checking engine performance. A typical fuel-flow indicator is illustrated in figure 10–69.

Engine Oil Pressure Indicator

To guard against engine failure resulting from inadequate lubrication and cooling of the various engine parts, the oil supply to critical areas must be monitored. The oil pressure indicator usually shows the engine-oil-pump discharge pressure.

Engine Oil Temperature Indicator

The ability of the engine oil to lubricate and cool depends on the temperature of the oil, as well as the amount of oil supplied to the critical areas. An oil-inlet temperature indicator frequently is provided to show the temperature of the oil as it enters the oil pressure pump. Oil-inlet temperature is also an indication of proper operation of the engine oil cooler.

TURBOJET ENGINE OPERATION

The engine operating procedures presented here apply generally to all turbojet engines. The procedures, pressures, temperatures, and r.p.m.'s which follow are intended primarily to serve as a guide. It should be understood that they do not have general application. The manufacturer's operating instructions should be consulted before attempting to start and operate a turbojet engine.

In contrast to the many controls for a reciprocating engine, a turbojet engine has only one power control lever. Adjusting the power lever or throttle sets up a thrust condition for which the fuel control meters fuel to the engine. Engines equipped with thrust reversers go into reverse thrust at throttle positions below "idle." A separate fuel shutoff lever is usually provided on engines equipped with thrust reversers.

Prior to start, particular attention should be paid to the engine air inlet, the visual condition and free movement of the compressor and turbine assembly, and the parking ramp area fore and aft of the aircraft. The engine is started by using an external power source or a self-contained, combustion-starter unit. Starter types and the engine starting cycle have been discussed previously. On multi-engine aircraft, one engine usually is started by a ground cart that supplies the air pressure for a pneumatic starter on the engine. Air bled from the first engine started then is used as a source of power for starting the other engines.

During the start, it is necessary to monitor the tachometer, the oil pressure, and the exhaust gas temperature. The normal starting sequence is: (1) Rotate the compressor with the starter, (2) turn the ignition on, and (3) open the engine fuel valve, either by moving the throttle to "idle" or by moving a fuel shutoff lever or turning a switch. Adherence to the procedure prescribed for a particular engine

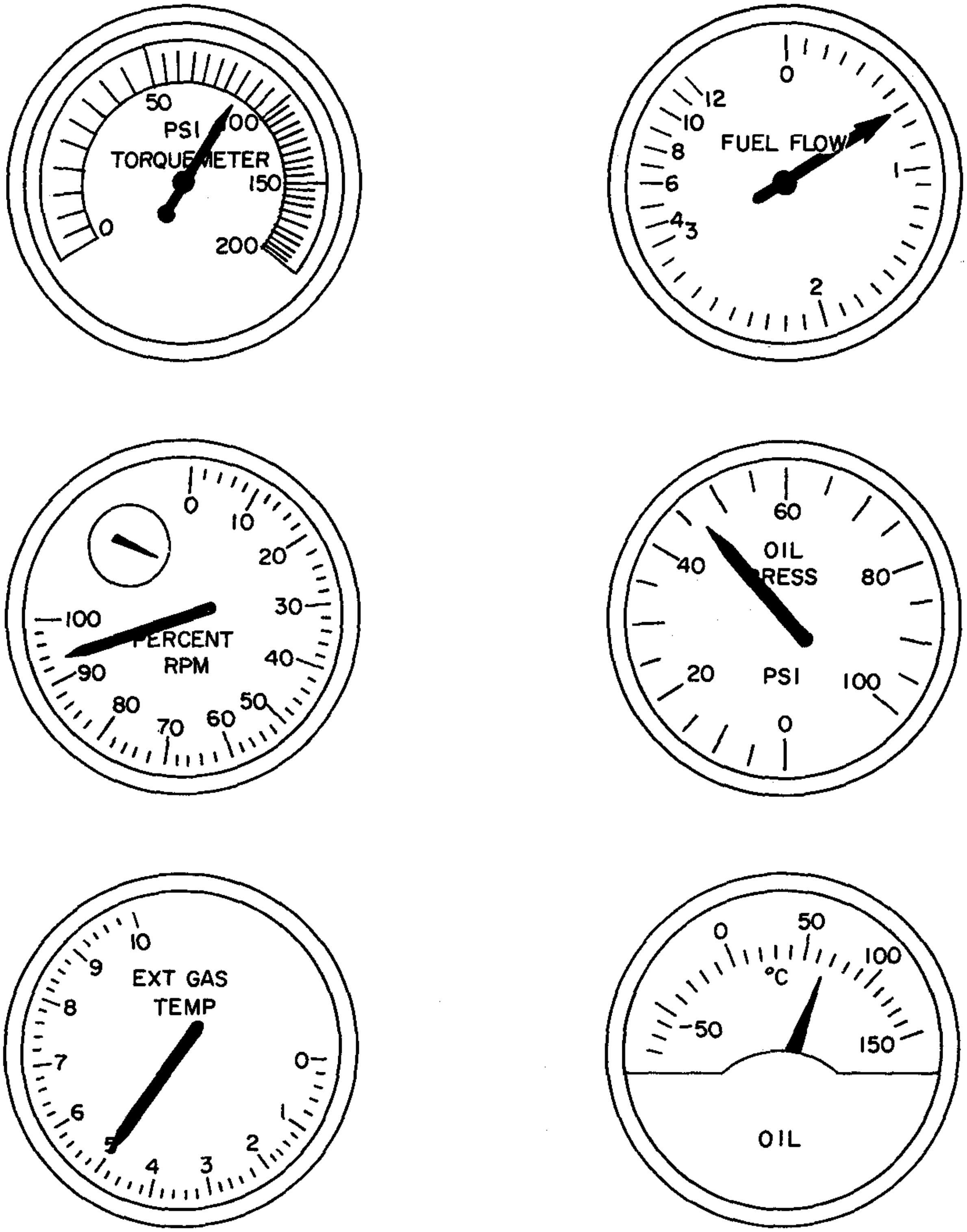


FIGURE 10–69. Typical turbine engine instruments.

is necessary as a safety measure and to avoid a "hot" or "hung" start.

A successful start will be noted first by a rise in exhaust gas temperature. If the engine does not "light up" within a prescribed period of time, or if the exhaust-gas-starting-temperature limit is exceeded, the starting procedure should be aborted. Hot starts are not common, but when they do occur, they can usually be stopped in time to avoid excessive temperature by observing the exhaust gas temperature constantly during the start. When necessary, the engine is cleared of trapped fuel or gases by continuing to rotate the compressor with the starter, but with the ignition and fuel turned off.

GROUND OPERATION

Engine Fire

If an engine fire occurs or if the fire warning light is illuminated during the starting cycle, move the fuel shutoff lever to the "off" position. Continue cranking or "motoring" the engine until the fire has been expelled from the engine. If the fire persists, CO_2 can be discharged into the inlet duct while it is being cranked. Do not discharge CO_2 directly into the engine exhaust because it may damage the engine. If the fire cannot be extinguished, secure all switches and leave the aircraft.

If the fire is on the ground under the engine overboard drain, discharge the CO_2 on the ground rather than on the engine. This also is true if the fire is at the tailpipe and the fuel is dripping to the ground and burning.

Engine Checks

Checking turbojet and turbofan engines for proper operation consists primarily of simply reading the engine instruments and then comparing the observed values with those known to be correct for any given engine operating condition.

Idle Checks

After the engine has started, idle r.p.m. has been attained, and the instrument readings have stabilized, the engine should be checked for satisfactory operation at idling speed. The oil pressure indicator, the tachometer, and the exhaust gas temperature readings should be compared with the allowable ranges. Fuel flow is not considered a completely reliable indication of engine condition at idling r.p.m. because of the inaccuracies frequently encountered in fuel flowmeters and indicators in the low range on the meters.

Checking Takeoff Thrust

Takeoff thrust is checked by adjusting the throttle to obtain a single, predicted reading on the engine pressure ratio indicator in the aircraft. The value for engine pressure ratio which represents takeoff thrust for the prevailing ambient atmospheric conditions is calculated from a takeoff thrust setting curve similar to that shown in figure 10–70.

This curve has been computed for static conditions. Therefore, for all precise thrust checking, the aircraft should be stationary, and stable engine operation should be established. If it is needed for calculating thrust during an engine trim check, turbine discharge pressure (P_{t7}) is also shown on these curves. Appropriate manuals should be consulted for the charts for a specific make and model engine.

The engine pressure ratio computed from the thrust setting curve represents either wet or dry takeoff thrust. The aircraft throttle is advanced to obtain this predicted reading on the engine pressure ratio indicator in the aircraft. If an engine develops the predicted thrust and if all the other engine instruments are reading within their proper ranges, engine operation is considered satisfactory.

Ambient Conditions

The sensitivity of gas turbine engines to compressor-inlet air temperature and pressure necessitates that considerable care be taken to obtain correct values for the prevailing ambient air conditions when computing takeoff thrust. Some things to remember are:

(1) The engine senses the air temperature and pressure at the compressor inlet. This will be the actual air temperature just above the runway surface. When the aircraft is stationary, the pressure at the compressor inlet will be the static field or true barometric pressure and not the barometric pressure corrected to sea level that is normally reported by airport control towers as the altimeter setting.

(2) Some airports provide the runway temperature, which should be used when available. The aircraft free air temperature indicator may or may not suffice for obtaining the temperature to be used, depending upon the manner in which the free air temperature is instrumented. If the thermometer bulb or thermocouple is exposed to the rays of the sun, the instrument reading will obviously not be accurate. When the control tower temperature must be used, a correction factor should be applied. For an accurate thrust computation, such as when trimming an engine, it is best to measure the actual temperature at the compressor inlet just before the engine is started, by means of a hand-held thermometer of known accuracy. When

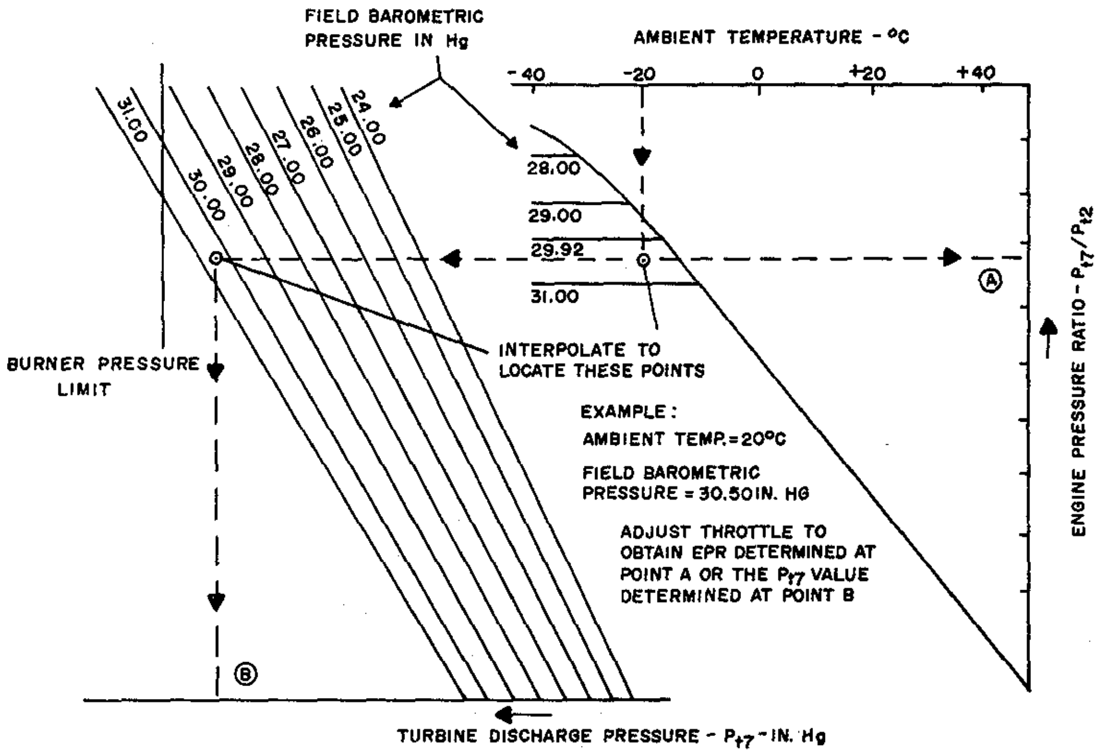


FIGURE 10–70. Typical takeoff thrust setting curve for static conditions.

it is realized that a 5° C. (9° F.) variation on compressor-inlet temperature will result in approximately 2 in. Hg variation in turbine discharge pressure, or 0.06 variation in engine pressure ratio indication, the importance of using the correct temperature for the thrust computation can be readily appreciated.

(3) If only the altimeter setting or the barometric pressure corrected to sea level is available when using the thrust setting curves to calculate turbine discharge pressure, this pressure must be re-corrected to field elevation. A method of obtaining the true pressure is to set the aircraft altimeter to zero altitude and read the field barometric pressure directly in the altimeter setting window on the face of the instrument. This method will work at all but the higher field elevations because of the limit of the altimeter setting scale.

(4) Relative humidity, which affects reciprocating engine power appreciably, has a negligible effect on turbojet engine thrust, fuel flow, and r.p.m. Therefore, relative humidity is not usually considered when computing thrust for takeoff or determining fuel flow and r.p.m. for routine operation.

ENGINE SHUTDOWN

On turbine engines, that do not have a thrust reverser, retarding the aircraft throttle or power lever to "off" cuts the fuel supply to the engine and shuts down the engine. On engines equipped with thrust reversers, this is accomplished by means of a separate fuel shutoff lever. An engine normally will be sufficiently cool to shut down immediately. However, as a rule of thumb, when an engine has been operated above approximately 85% r.p.m. for periods exceeding 1 min. during the last 5 min. prior to shutdown, it is recommended the engine be operated below 85% r.p.m. (preferably at idle) for a period of 5 min. to prevent possible seizure of the rotors. This applies, in particular, to prolonged operation at high r.p.m. on the ground, such as during engine trimming.

The turbine case and the turbine wheels operate at approximately the same temperature when the engine is running. However, the turbine wheels are relatively massive, compared with the case, and are not cooled so readily. The turbine case is exposed to cooling air from both inside and outside the engine. Consequently, the case and the wheels lose their residual heat at different rates after the engine has been shut down. The case, cooling faster, tends to shrink upon the wheels, which are still rotating. Under extreme conditions, the turbine blades may squeal or seize; thus a cooling period is required if the engine has been operating at prolonged high speed. Should the turbine wheels seize, no harm will normally result, provided no attempt is made to turn the engine over until it has cooled sufficiently to free the wheels. In spite of this, every effort should be made to avoid seizure.

The aircraft fuel boost pump must be turned off after, not before, the throttle or the fuel shutoff lever is placed in the off position, to ensure that fuel remains in the lines and that the engine-driven fuel pumps do not lose their prime. Under such conditions, the aircraft fuel boost pump usually is unable to re-prime the engine-driven fuel pump without air being bled from the fuel control.

Generally, an engine should not be shut down by the fuel shutoff lever until after the aircraft throttle has been retarded to "idle." Because the fuel shutoff valve is located on the fuel control discharge, a shutdown from high thrust settings will result in high fuel pressures within the control that can harm the fuel system parts.

When an accurate reading of the oil level in the oil tank is needed following an engine shutdown, the engine should be operated at approximately 75% r.p.m. for not less than 15 nor more than 30 sec. immediately before shutdown to properly scavenge oil from inside the engine.

TROUBLESHOOTING TURBOJET ENGINES

Included in this section are typical guidelines for locating engine malfunctions on most turbojet engines. Since it would be impractical to list all the malfunctions that could occur, only the most common malfunctions are covered. A thorough knowledge of the engine systems, applied with logical reasoning, will solve any problems which may occur.

Table 12 enumerates some malfunctions which may be encountered. Possible causes and suggested actions are given in the adjacent columns. The malfunctions presented herein are solely for the purpose of illustration and should not be construed to have general application. ***For exact information about a specific engine model, consult the applicable manufacturer's instructions.***

TURBOPROP OPERATION

Turboprop engine operation is quite similar to that of a turbojet engine, except for the added feature of a propeller. The starting procedure and the various operational features are very much alike. The turboprop chiefly requires attention to engine operating limits, the throttle or power lever setting, and the torquemeter pressure gage. Although torquemeters indicate only the power being supplied to the propeller and not the equivalent shaft horsepower, torquemeter pressure is approximately proportional to the total power output and, thus, is used as a measure of engine performance. The torquemeter pressure gage reading during the takeoff engine check is an important value. It is usually necessary to compute the takeoff power in the same manner as is done for a turbojet engine. This computation is to determine the maximum allowable exhaust gas temperature and the torquemeter pressure that a normally functioning engine should produce for the outside (ambient) air temperature and barometric pressure prevailing at the time.

TABLE 12. Troubleshooting turbojet engines.

Indicated malfunction	Possible cause	Suggested action
Engine has low r.p.m., exhaust gas temperature, and fuel flow when set to expected engine pressure ratio.	Engine pressure ratio indication has high reading error.	Check inlet pressure line from probe to transmitter for leaks.
		Check engine pressure ratio transmitter and indicator for accuracy.
Engine has high r.p.m., exhaust gas temperature, and fuel flow when set to expected engine pressure ratio.	Engine pressure ratio indication has low reading error due to:	
	Misaligned or cracked turbine discharge probe.	Check probe condition.
	Leak in turbine discharge pressure line from probe to transmitter.	Pressure-test turbine discharge pressure line for leaks.
	Inaccurate engine pressure ratio transmitter or indicator.	Check engine pressure ratio transmitter and indicator for accuracy.

TABLE 12. Troubleshooting turbojet engines—con.

Indicated malfunction	Possible cause	Suggested action
	Carbon particles collected in turbine discharge pressure line or restrictor orifices.	
Engine has high exhaust gas temperature, low r.p.m., and high fuel flow at all engine pressure ratio settings.	Possible turbine damage and/or loss of turbine efficiency.	Confirm indication of turbine damage by: Checking engine coast-down for abnormal noise and reduced time. Visually inspect turbine area with strong light.
NOTE: Engines with damage in turbine section may have tendency to hang up during starting.	If only exhaust gas temperature is high, other parameters normal, the problem may be thermocouple leads or instrument.	Re-calibrate exhaust gas temperature instrumentation.
Engine vibrates throughout r.p.m. range, but indicated amplitude reduces as r.p.m. is reduced.	Turbine damage.	Check turbine as outlined in preceding item.
Engine vibrates at high r.p.m. and fuel flow when compared to constant engine pressure ratio.	Damage in compressor section.	Check compressor section for damage.
Engine vibrates throughout r.p.m. range, but is more pronounced in cruise or idle r.p.m. range.	Engine-mounted accessory such as constant-speed drive, generator, hydraulic pump, etc.	Check each component in turn.
No change in power setting parameters, but oil temperature high.	Engine main bearings.	Check scavenge oil filters and magnetic plugs.
Engine has higher-than-normal exhaust gas temperature during takeoff, climb, and cruise. R.P.M. and fuel flow higher than normal.	Engine bleed-air valve malfunction.	Check operation of bleed valve.
	Turbine discharge pressure probe or line to transmitter leaking.	Check condition of probe and pressure line to transmitter.
Engine has high exhaust gas temperature at target engine pressure ratio for takeoff.	Engine out of trim.	Check engine with jetcal. Re-trim as desired.
Engine rumbles during starting and at low power cruise conditions.	Pressurizing and drain valve malfunction.	Replace pressurizing and drain valves.
	Cracked air duct.	Repair or replace duct.
	Fuel control malfunction.	Replace fuel control.
Engine r.p.m. hangs up during starting.	Subzero ambient temperatures.	If hang-up is due to low ambient temperature, engine usually can be started by turning on fuel booster pump or by positioning start lever to run earlier in the starting cycle.
	Compressor section damage.	Check compressor for damage.
	Turbine section damage.	Inspect turbine for damage.
High oil temperature.	Scavenge pump failure.	Check lubricating system and scavenge pumps.
	Fuel heater malfunction.	Replace fuel heater.
High oil consumption.	Scavenge pump failure.	Check scavenge pumps.
	High sump pressure.	Check sump pressure as outlined in manufacturer's maintenance manual.
	Gearbox seal leakage.	Check gearbox seal by pressurizing overboard vent.
Overboard oil loss.	Can be caused by high airflow through the tank, foaming oil, or unusual amounts of oil returned to the tank through the vent system.	Check oil for foaming; vacuum-check sumps; check scavenge pumps.

TROUBLESHOOTING PROCEDURES FOR TURBOPROP ENGINES

All test run-ups, inspections, and troubleshooting should be performed in accordance with the applicable engine manufacturer's instructions. In table 13, the troubleshooting procedures for the turboprop reduction gear, torquemeter, and power sections are combined because of their inter-relationships. The table includes the principal troubles, together with their probable causes and remedies.

TABLE 13. Troubleshooting turboprop engines.

Trouble	Probable cause	Remedy
Power unit fails to turn over during attempted start.	No air to starter.	Check starter air valve solenoid and air supply.
	Propeller brake locked.	Unlock brake by turning propeller by hand in direction of normal rotation.
Power unit fails to start.	Starter speed low because of inadequate air supply to starter.	Check starter air valve solenoid and air supply.
	If fuel is not observed leaving the exhaust pipe during start, fuel selector valve may be inoperative because of low power supply or may be locked in "off."	Check power supply or electrically operated valves. Replace valves if defective.
	Fuel pump inoperative.	Check pump for sheared drives or internal damage; check for air leaks at outlet.
	Aircraft fuel filter dirty.	Clean filter and replace filtering elements if necessary.
	Fuel control cutoff valve closed.	Check electrical circuit to ensure that actuator is being energized. Replace actuator or control.
Engine fires, but will not accelerate to correct speed.	Insufficient fuel supply to control unit.	Check fuel system to ensure all valves are open and pumps are operative.
	Fuel control main metering valve sticking.	Flush system. Replace control.
	Fuel control bypass valve sticking open.	Flush system. Replace control.
	Drain valve stuck open. Starting fuel enrichment pressure switch setting too high.	Replace drain valve. Replace pressure switch.
Acceleration temperature too high during starting.	Fuel control bypass valve sticking closed.	Flush system. Replace control.
	Fuel control acceleration cam incorrectly adjusted.	Replace control.
	Defective fuel nozzle.	Replace nozzle with a known satisfactory unit.
	Fuel control thermostat failure.	Replace control.
Acceleration temperature during starting too low.	Acceleration cam of fuel control incorrectly adjusted.	Replace control.
Engine speed cycles after start.	Unstable fuel control governor operation.	Continue engine operation to allow control to condition itself.
Power unit oil pressure drops off severely.	Oil supply low.	Check oil supply and refill as necessary.
	Oil pressure transmitter or indicator giving false indication.	Check transmitter or indicator and repair or replace if necessary.

TABLE 13. Troubleshooting turboprop engines—con.

Trouble	Probable cause	Remedy
Oil leakage at accessory drive seals.	Seal failure	Replace seal or seals.
Engine unable to reach maximum controlled speed of 100%.	Faulty propeller governer.	Replace propeller control assembly.
	Faulty fuel control or air sensing tip.	Replace faulty control. If dirty, use air pressure in reverse direction of normal flow through internal engine passage and sensing tip.
Vibration indication high.	Vibration pickup or vibration meter malfunctioning.	Calibrate vibration meter. Start engine and increase power gradually. Observe vibration indicator. If indications prove pickup to be at fault, replace it. If high vibration remains as originally observed, remove power unit for overhaul.

JET CALIBRATION TEST UNIT

Two of the most important factors affecting turbine engine life are EGT (exhaust gas temperature) and engine speed. Excess EGT of a few degrees will reduce turbine blade life as much as 50%. Low exhaust gas temperature materially reduces turbine engine efficiency and thrust. Excessive engine speed can cause premature engine failure.

Indications of fuel system troubles, tailpipe temperature, and r.p.m. can be checked more accurately from the jet calibration test unit than from the gages in the cockpit of the aircraft. Errors up to 10° C. may be made in the interpretation of the temperature gages because of the height of the observer in the seat. Similarly, errors may be made in interpretation of tachometers. With proper utilization of the jet calibration test unit, such errors can be reduced greatly.

One type of calibration test unit used to analyze the turbine engine is the jetcal analyzer (figure 10–71). A jetcal analyzer is a portable instrument made of aluminum, stainless steel, and plastic. The major components of the analyzer are the thermocouple, r.p.m., EGT indicator, resistance, and insulation check circuits, as well as the potentiometer, temperature regulators, meters, switches, and all the necessary cables, probes, and adapters for performing all tests. A jetcal analyzer also includes fire warning overheat detection and wing anti-icing system test circuits.

Jetcal Analyzer Uses

The jetcal analyzer may be used to:

(1) Functionally check the aircraft EGT system for error without running the engine or disconnecting the wiring.

(2) Check individual thermocouples before placement in a parallel harness.

(3) Check each engine thermocouple in a parallel harness for continuity.

(4) Check the thermocouples and parallel harness for accuracy.

(5) Check the resistance of the EGT circuit.

(6) Check the insulation of the EGT circuit for shorts to ground, or for shorts between leads.

(7) Check EGT indicators (either in or out of the aircraft) for error.

(8) Determine engine r.p.m. with an accuracy of ±0.1% during engine run-up. Added to this is the checking and troubleshooting of the aircraft tachometer system.

(9) Establish the proper relationship between the EGT and engine r.p.m. on engine run-up during tabbing (micing) procedures by the r.p.m. check (takcal) and potentiometer in the jetcal analyzer. (Tabbing procedures are those procedures followed when adjusting fixed exhaust nozzle exit areas.)

(10) Check aircraft fire detector, overheat detector, and wing anti-icing systems by using tempcal probes.

Operating Instructions for the Jetcal Tester

The complete step-by-step procedure on the instruction plate of the jetcal analyzer can be followed during actual operation of the analyzer. The operation plate is visible at all times when operating the analyzer.

It would be useless to list the step-by-step procedure in this section. The procedure consists of turning on or off many separate switches and dials.

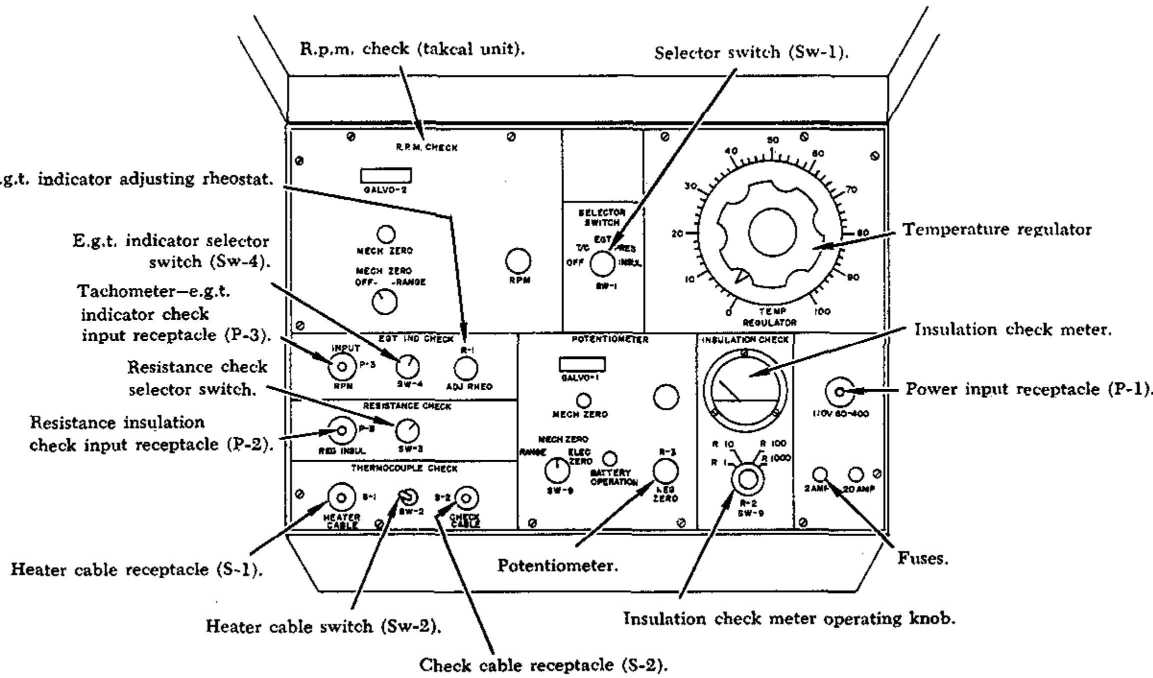


FIGURE 10–71. Jetcal analyzer instrument compartment.

To avoid confusion, this section will be confined to the operation of the jetcal analyzer in a general sense.

Safety Precautions

Observe the following safety precautions while operating the jetcal analyzer:

(1) Never use a volt-ohmmeter to check the potentiometer for continuity. If a volt-ohmmeter is used, damage to the galvanometer and standard battery cell will result.

(2) Check the thermocouple harness before engine run-up. This must be done because the circuit must be correct before the thermocouples can be used for true EGT pickup.

(3) For safety, ground the jetcal analyzer when using an a.c. power supply. Any electrical equipment operated on a.c. power and utilizing wire-wound coils, such as the probes with the jetcal analyzer, has an induced voltage on the case that can be discharged if the equipment is not grounded. This condition is not apparent during dry weather, but on damp days the operator can be shocked slightly. Therefore, for the operator's protection, the jetcal analyzer should be grounded using the pigtail lead in the power inlet cable.

(4) Use heater probes designed for use on the engine thermocouples to be tested. Temperature gradients are very critical in the design of heater probes. Each type of aircraft thermocouple has its own specially designed probe. Never attempt to modify heater probes to test other types of thermocouples.

(5) Do not leave heater probes assemblies in the tailpipe during engine run-up.

(6) Never allow the heater probes to go over 900° C. (1,652° F.). Exceeding these temperatures will result in damage to the jetcal analyzer and heater probe assemblies.

Continuity Check of Aircraft EGT Circuit

To eliminate any error caused by one or more inoperative aircraft thermocouples, a continuity check is performed. The check is made by heating one heater probe to between 500° and 700° C. and placing the hot probe over each of the aircraft thermocouples, one at a time. The EGT indicator must show a temperature rise as each thermocouple is checked. When large numbers of thermocouples are used in the harness (eight or more), it is difficult to see a rise on the aircraft instrument because of the electrical characteristics of a parallel circuit. Therefore, the temperature indication of the aircraft thermocouples is read on the potentiometer of the jetcal analyzer by using the check cable and necessary adapter.

Functional Check of Aircraft EGT Circuit

The time required to test the EGT system of any one aircraft will depend on several factors: (1) The number of engines; (2) the number of thermocouples in the harness, and their position in the engine; (3) the errors, if any are found; and (4) the time required to correct the errors. The normal functional test of a single engine can be performed in 10 to 20 min.; special conditions may require more time.

During the EGT system functional test and the thermocouple harness checks, the jetcal analyzer has a guaranteed accuracy of $\pm 4°$ C. at the test temperature, which is usually the maximum operating temperature of the jet engine. Each engine has its own maximum operating temperature, which can be found in applicable technical instructions.

The test is made by heating the engine thermocouples in the tail cone to the engine test temperature. The heat is supplied by heater probes through the necessary cables. With the engine thermocouples hot, their temperature is registered on the aircraft EGT indicator. At the same time, the thermocouples embedded in the heater probes, which are completely isolated from the aircraft system, are picking up and registering the same temperature on the jetcal analyzer.

The temperature registered on the aircraft EGT indicator (figure 10–72) should be within the specified tolerance of the aircraft system and the temperature reading on the jetcal potentiometer. The thermocouples embedded in the heater probes are of U.S. Bureau of Standards accuracy; therefore, jetcal readings are accepted as the standard and are used as the basis of comparison for checking the accuracy of the aircraft EGT system.

Since the junction box is wired in parallel, it is not necessary to have heater probes connected to all the outlets of the junction box when making a check. On engines that have a balancing type thermocouple system, the balancing thermocouple must be removed from the circuit. The remaining thermocouples can be checked individually or together. The balancing thermocouple is checked, using a single probe. The output of the balancing thermocouple is also read on the jetcal potentiometer and compared to the heater probe thermocouple reading.

When the temperature difference exceeds the allowable tolerance, troubleshoot the aircraft system

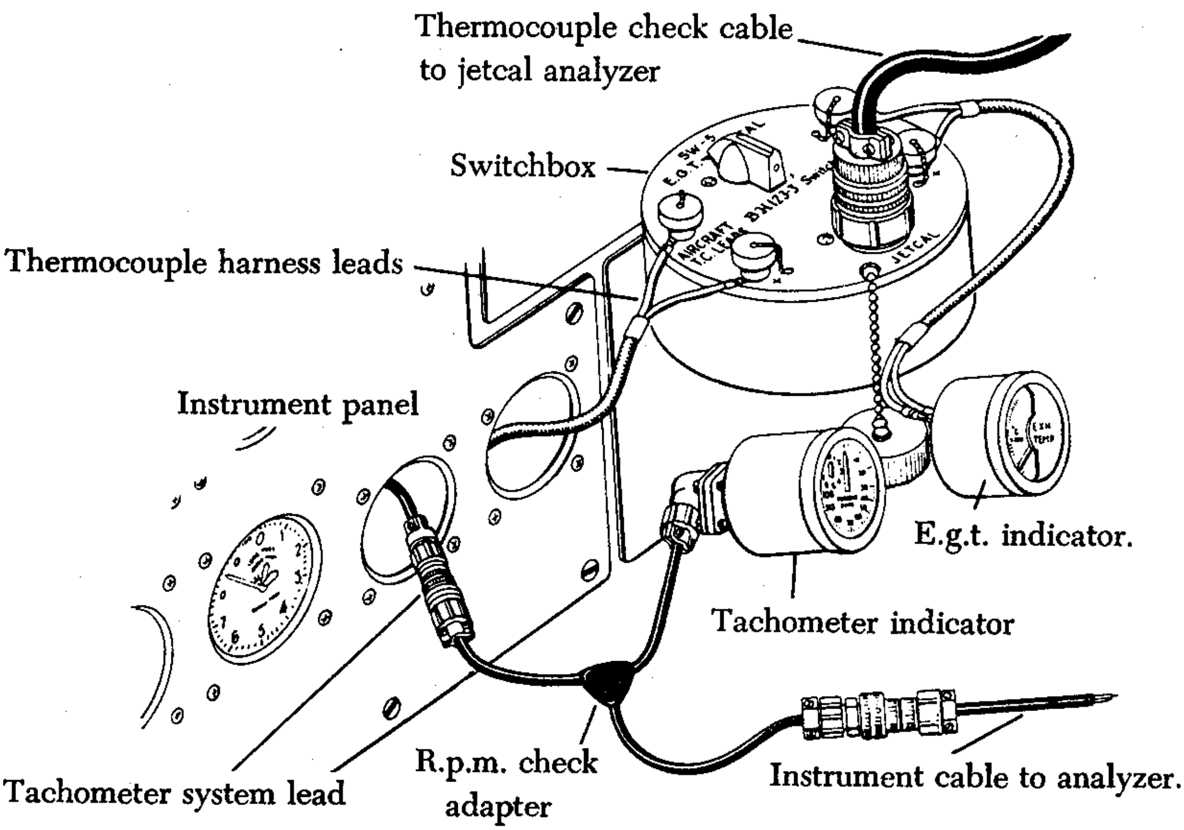


FIGURE 10–72. Switchbox and r.p.m. check adapter connections.

to determine which parts are in error. Troubleshooting is discussed at the end of this section.

Functional Test of Thermal Switches

The tempcal probe functionally tests the operation of the fire detection, overheat, and wing anti-icing systems that incorporate a thermal switch as the detection device. Test the thermal switch in position on the aircraft by placing the probe over the thermal switch. The tempcal probe incorporates the principles of the heater probe for its temperature pickup. The temperature is controlled by the temperature regulator and is read on the jetcal potentiometer.

With the tempcal probe over the thermal switch, the temperature of the probe is raised and lowered to take the switch through its operating temperatures. The indicator on the aircraft instrument panel, generally a red light, then is checked for indication to make sure that the switch is actuating at proper temperatures. If the system is not indicating properly, the circuit must be corrected.

If a hot tempcal probe is placed over a cold thermal switch, the contacts will close almost immediately due to an action called "thermal shock." As the thermal switch continues to absorb heat, the contacts will open and then close again when the operating temperature of the switch is reached.

EGT Indicator Check

The EGT indicator is tested after being removed from the aircraft instrument panel and disconnected from the aircraft EGT circuit leads. Attach the instrument cable and EGT indicator adapter leads to the indicator terminals and place the indicator in its normal operating position. Adjust jetcal analyzer switches to the proper settings. The indicator reading should correspond to the potentiometer readings of the jetcal analyzer within the allowable limits of the EGT indicator.

Correction for ambient temperature is not required for this test, as both the EGT indicator and jetcal analyzer are temperature compensated.

The temperature registered on the aircraft EGT indicator should be within the specified tolerance of the aircraft system and the temperature reading on the jetcal potentiometer. When the temperature difference exceeds the allowable tolerance, troubleshoot the aircraft system to determine which parts are in error.

Resistance and Insulation Check

The thermocouple harness continuity is checked while the EGT system is being checked functionally. The resistance of the thermocouple harness is held to very close tolerances, since a change in resistance changes the amount of current flow in the circuit. A change of resistance will give erroneous temperature readings.

The resistance and insulation check circuits make it possible to analyze and isolate any error in the aircraft system. How the resistance and insulation circuits are used will be discussed with troubleshooting procedures.

Tachometer Check

To read engine speed with an accuracy of $\pm 0.1\%$ during engine run, the frequency of the tachometer-generator is measured by the r.p.m. check (takcal) circuit in the jetcal analyzer. The scale of the r.p.m. check circuit is calibrated in percent r.p.m. to correspond to the aircraft tachometer indicator, which also reads in percent r.p.m. The calibration intervals are 0.2%. The aircraft tachometer and the r.p.m. check circuit are connected in parallel, and both are indicating during engine run-up.

The r.p.m. check circuit readings can be compared with the readings of the aircraft tachometer to determine the accuracy of the aircraft instrument.

Troubleshooting EGT System

The jetcal analyzer is used to test and troubleshoot the aircraft thermocouple system at the first indication of trouble or during periodic maintenance checks.

The test circuits of the jetcal analyzer make it possible to isolate all the troubles listed below. Following the list is a discussion of each trouble mentioned.

(1) One or more inoperative thermocouples in engine parallel harness.

(2) Engine thermocouples out of calibration.

(3) EGT indicator error.

(4) Resistance of circuit out of tolerance.

(5) Shorts to ground.

(6) Shorts between leads.

One or More Inoperative Thermocouples in Engine Parallel Harness

This error is found in the regular testing of aircraft thermocouples with a hot heater probe and will be a broken lead wire in the parallel harness or a short to ground in the harness. In the latter case the current from the grounded thermocouple can leak off and never be shown on the indicator.

However, this grounded condition can be found by using the insulation resistance check.

Engine Thermocouples Out of Calibration

When thermocouples are subjected for a period of time to oxidizing atmospheres, such as encountered in turbine engines, they will drift appreciably from their original calibration. On engine parallel harnesses, when individual thermocouples can be removed, these thermocouples can be bench-checked, using one heater probe. The temperature reading obtained from the thermocouples should be within manufacturer's tolerances.

EGT Circuit Error

This error is found by using the switchbox and comparing the reading of the aircraft EGT indicator with the jetcal temperature reading (figure 10–72). With switch (SW-5) in the jetcal position, the indication of the thermocouple harness is carried back to the jetcal analyzer. With the switch (SW-5) in the EGT position, the temperature reading of the thermocouple harness is indicated on the aircraft EGT indicator. The jetcal and aircraft temperature readings are then compared.

Resistance of Circuit Out of Tolerance

The engine thermocouple circuit resistance is a very important adjustment since a high-resistance condition will give a low indication on the aircraft EGT indicator. This condition is dangerous, because the engine will be operating with excess temperature, but the high resistance will make the indicator read low. Adjusting a resistor and/or a resistance coil in the EGT circuit generally corrects this condition.

Shorts to Ground and Shorts Between Leads

These errors are found by using the insulation check meter as an ohmmeter. Resistance values from zero to 550,000 ohms can be read on the insulation check meter by selecting the proper range.

TROUBLESHOOTING AIRCRAFT TACHOMETER SYSTEM

A related function of the r.p.m. check is troubleshooting the aircraft tachometer system. The r.p.m. check circuit in the jetcal analyzer is used to read engine speed during engine run-up with an accuracy of $\pm 0.1\%$. The connections for the r.p.m. check are the instrument cable, and aircraft tachometer system lead to the tachometer indicator (figure 10–72). After the connections have been made between the jetcal analyzer r.p.m. check circuit and the aircraft tachometer circuit, the two circuits (now classed as one) will be a parallel circuit. The engine is then run-up as prescribed in applicable technical instructions. Both systems can be read simultaneously.

If the difference between the readings of the aircraft tachometer indicator and the jetcal analyzer r.p.m. check circuit exceeds the tolerance prescribed in applicable technical instructions, the engine must be stopped, and the trouble located and corrected. The following steps will assist in locating and isolating the trouble:

(1) If the aircraft tachometer error exceeds the authorized tolerance when compared to the r.p.m. check readings, the instrument should be replaced.

(2) If it is impossible to read 100% r.p.m. on the aircraft tachometer, but the r.p.m. check circuit does read 100% r.p.m., the trouble will be a bad aircraft tachometer indicator or a bad tachometer-generator. Replace the defective parts.

(3) If there is no reading on the aircraft tachometer indicator, but there is a reading on the r.p.m. check circuit, the trouble will either be a bad aircraft tachometer or an open or a grounded phase from the aircraft tachometer-generator. Replace the defective aircraft tachometer or tachometer-generator, or repair the defective lead.

(4) If there is no r.p.m. indication on either the aircraft tachometer or the jetcal analyzer r.p.m. check circuit, there will be an open or shorted lead in the aircraft circuit or a defective tachometer-generator. The defect in the aircraft circuit should be located and corrected, or the tachometer-generator should be replaced. The engine r.p.m. reading should be repeated to check parts replaced as a result of the above tests.

The jetcal analyzer is used for engine tabbing because engine speed and exhaust temperature are extremely critical in engine operation. When the engine is to be checked and tabbed, the most convenient way to do this is to put the switchbox in the EGT circuit and make the connections for the r.p.m. check at the beginning of the test.

The switchbox is used either to switch the EGT indicator into the circuit or to switch the temperature indication of the engine thermocouple harness to the jetcal potentiometer. However, temperature readings from the aircraft thermocouple harness can be made by connecting the check cable (with or without adapter) to the engine junction box (see figure 10–73). The aircraft EGT indicator must be used when the engine is started to be able to detect a hot start.

The engine is started and brought to the speed specified in applicable technical instructions. During tabbing procedures, all engine speed readings are made on the r.p.m. check in the jetcal analyzer, and engine temperature readings are made on the jetcal potentiometer. This is necessary because engine temperature and speed must be read accurately during engine tabbing to assure that the engine is operating at optimum engine conditions.

If the temperature reading is not within the tolerances stated in applicable instructions, the engine is stopped and tabs are added or removed as required. The engine is run-up and r.p.m. and temperature readings are again taken to make sure that the tabs added or removed bring the tailpipe temperature within tolerance.

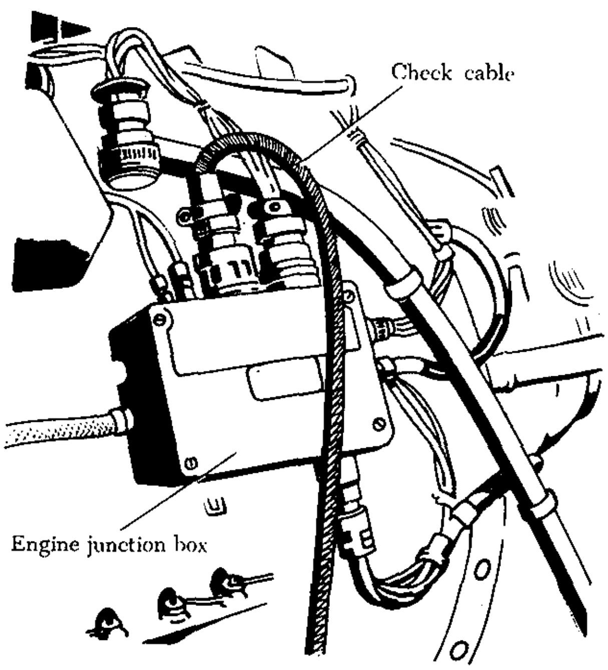


FIGURE 10–73. Check cable connected to engine junction box.

SPECTROMETRIC OIL ANALYSIS PROGRAM

The spectrometric oil analysis program has been used by branches of aviation for several years. It is based on the fact that each element will display a certain pattern of light when a sample is used in a spectrometer. It is applicable to either reciprocating or turbine engines.

The spectrometric analysis for metal content is possible because metallic atoms and ions emit characteristic light spectra when vaporized in an electric arc or spark. The spectrum produced by each metal is unique for that metal. The position or wave length of a spectral line will identify the particular metal, and the intensity of the line can be used to measure the quantity of the metal in a sample.

How the Analyzer Works

Periodic samples of used oil are taken from all equipment protected by the program and sent to an oil analysis laboratory. Here is a brief description of how the spectrometer measures the wear metals present in the used oil samples:

(1) A film of the used oil sample is picked on the rim of a rotating, high-purity, graphite disc electrode. (See figure 10–74.)

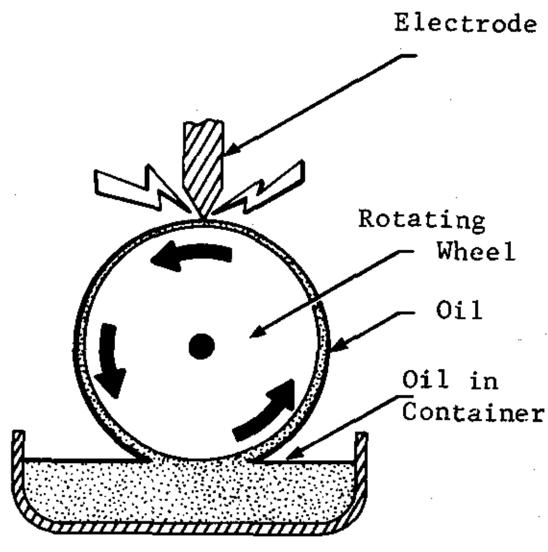


FIGURE 10–74. Oil Sample

(2) Precisely controlled, high voltage, ac spark discharge is initiated between the vertical electrode and the rotating disc electrode burning the small film of oil.

(3) Light from the burning oil passes through a slit which is positioned precisely to the wave length for the particular wear metal being monitored. (See figure 10–75.)

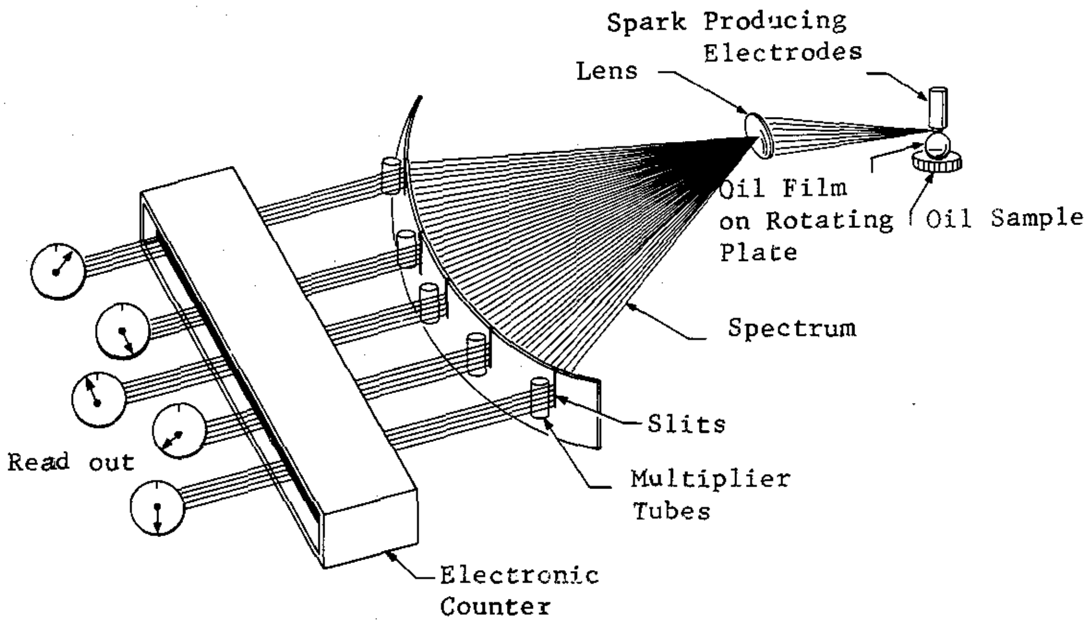


FIGURE 10–75. Spectrometic Analysis of Metals

(4) As the light passes through the slits, photomultiplier tubes transform the light waves electronically into energy which automatically prints the analytical results in parts per million on punch cards on the laboratory record sheets.

(5) The results are interpreted and when a sharp trend or abnormal concentration of metal is present, the participant is notified by telephone or message, depending on the urgency.

Application

Under certain conditions and within certain limitations, the internal condition of any mechanical system can be evaluated by the spectrometric analysis of lubricating oil samples. The concept and application are based on the following facts:

(1) The components of aircraft mechanical systems contain aluminum, iron, chromium, silver, copper, tin, magnesium, lead and nickel as the predominant alloying elements.

(2) The moving contact between the metallic components of any mechanical system is always accompanied by friction. Even though this friction is reduced by a thin film of oil, some microscopic particles of metal do wear away and are carried in suspension in the oil. Thus, a potential source of information exists that relates directly to the condition of the system. The chemical identity of the worn surfaces and the particles worn from those surfaces will always be the same. If the rate of each kind of metal particle can be measured and established as being normal or abnormal, then the rate of wear of the contacting surfaces will also be established as normal or abnormal. The chemical identity of the abnormally produced particles will provide clues to the identity of the components being worn.

Under most conditions, the rate of wear will remain constant and quite slow. The wear metal particles will be microscopic in size so that the particles will remain in suspension in the lubricating system.

Any condition, which alters or increases the normal friction between the moving parts, will also accelerate the rate of wear and increase the quantity of wear particles produced. If the condition is not discovered and corrected, the wear process will continue to accelerate, usually with secondary damage to other parts of the system and eventual failure of the entire system will occur.

Measurement of the Metals

The important wear metals produced in an oil lubrication mechanical system can be separately measured in extremely low concentrations by the spectrometric analysis of oil samples taken from the system.

Silver is accurately measured in concentrations down to one-half part by weight of silver in 1,000,000 parts of oil. Most other metals are measured accurately in concentrations down to two or three parts per million. The maximum amount of normal wear has been determined for each metal of the particular system in the program. This amount is called its threshold limit of contamination and is measured by weight in parts per million (PPM).

It must be understood that the wear metals present are of such microscopic size that they can not be seen by the naked eye, cannot be felt with the fingers, and flow freely through the system filters. As an example, wear metals one-tenth the size of a grain of talcum powder, are easily measured by the spectrometer. The spectrometer therefore measures the particles that move in suspension in the oil and are too small to appear on either the oil screen or chip detector.

Advantages

The Oil Analysis Program is not a cure-all, as normal maintenance practices must still be followed. There are several side benefits of the program worth mentioning, however.

Analysis of oil samples after a maintenance action has been accomplished can be used as a quality control tool by maintenance. An analysis which continues to show abnormal concentrations of wear metals present in the system would be positive proof that maintenance had not corrected the discrepancy and further trouble-shooting techniques must be employed.

Analysis of samples from engines on test stands has reduced the possibility of installing a newly overhauled engine in the aircraft that contains discrepancies not detected by test stand instruments.

Spectrometric oil analysis has been used mainly in analyzing conditions of reciprocating, turbo-prop and turbo-jet engines and helicopter transmissions. Impending failures were predicted before advancing to inflight failures. Numerous reciprocating engines have been repaired in the field by replacement of a cylinder instead of replacement of an entire engine. The technique is also applicable to constant speed drives, cabin superchargers, gear boxes, hydraulic systems, and other oil-wetted mechanical systems.

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